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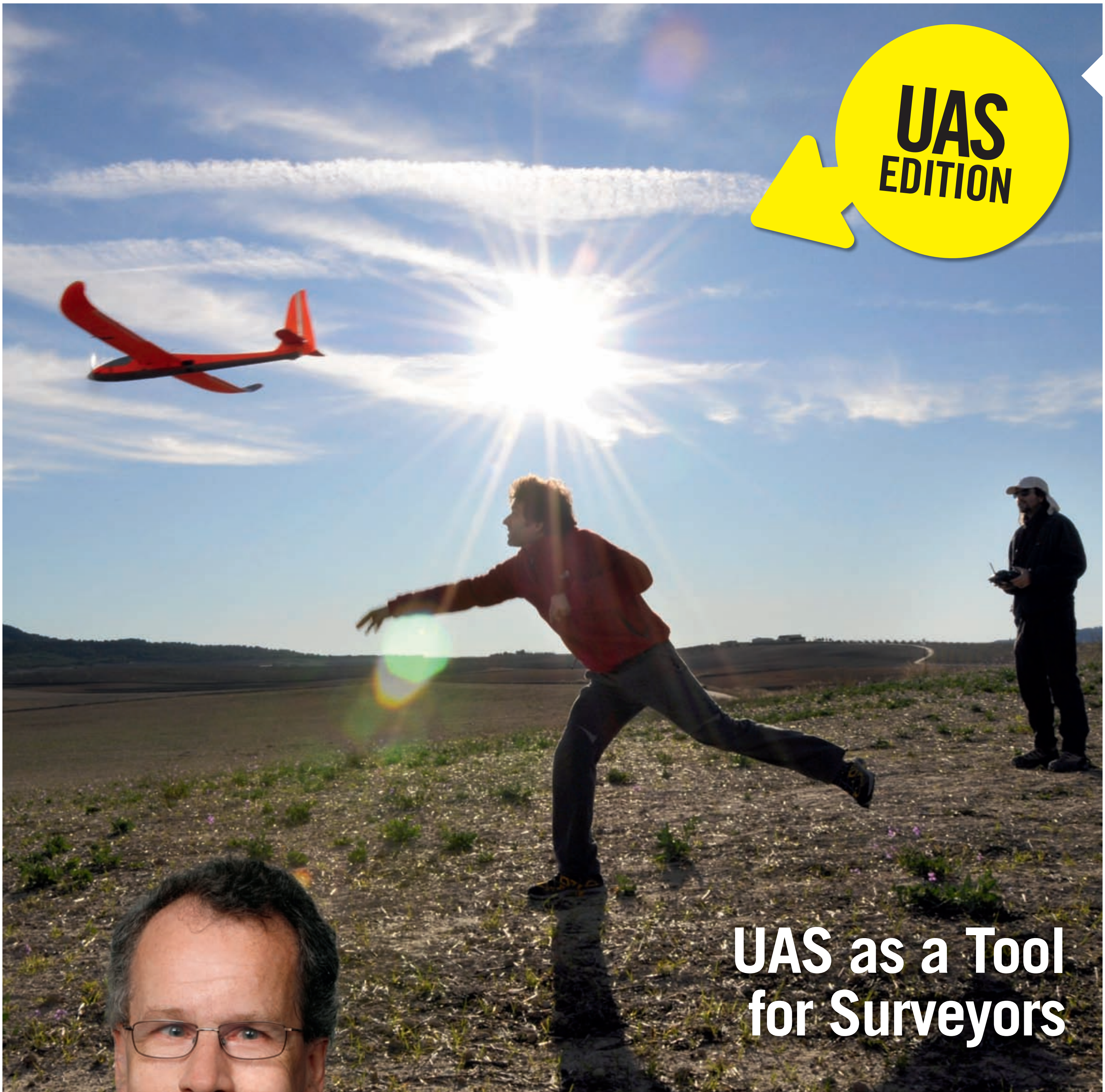

UAS EDITION

UAS as a Tool for Surveyors

GIM International Interviews
Christian Heipke

UAS for Mining
Accuracy Assessment, Time Savings and Safety

Experiences in UAS Photogrammetry
Quality Matters

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Place under the Sun

Welcome to this very special issue of *GIM International*, dedicated to one of the most groundbreaking technologies seen in geomatics in recent years: unmanned aerial systems (UAS). The ability to capture data remotely is greatly increasing the possibilities for geomatics professionals and others to perform mapping and surveying work in isolated or harsh environments in which it has so far been difficult to acquire data. UAS fill gaps we have previously not been able to fill. Also, the economic aspect should not to be forgotten: deploying UAS increases the speed of data acquisition and hence the efficiency of the industry. We've noticed immense interest in the series of UAS articles published in *GIM International* since the beginning of this year, so we have picked a selection for you to read in this special edition. We've covered a wide range of topics: UAS as a tool for cadastral surveys, experiences with UAS in photogrammetry, and UAS in the mountains. We've also touched on issues relating to privacy and security since these are inextricably linked to the use of UAS in certain areas. We've opted for virtual surveying, described by Tom Op 't Eyndt and Walter Volkmann in their article 'UAS as a Tool for Surveyors', to be republished in this special edition [page 26] as well as Mikko Sippo's article describing his experiences in UAS photogrammetry [page 12]. Meanwhile, Willem van Hinsbergh, Martijn Rijsdijk and Wim Witteveen's feature 'UAS for Cadastral Applications' which previously appeared in *GIM International* is republished here [page 17]. The article by Craig Vorster and Christoph Strecha on UAS for Mining [page 22] is a new article written especially for this edition. Furthermore, we interviewed professor Christian Heipke, president of the International Society of Photogrammetry and Remote Sensing, on the benefits and dangers of UAS. Prof Heipke sees a definite place under the sun for UAS in the range of acquisition techniques that will fill the gap between aerial and terrestrial surveys. And although there are still some issues to be resolved – not only privacy, but also flying time – the technique is way too promising to be hindered in its development into maturity. The best way to gain traffic during an industry exhibition these days is by showing off – preferably with live demos – Unmanned Aerial Vehicles on the show floor. The crowds are bound to gaze at this technical wonder that will ultimately enter the lives of many geomatics professionals. We are keen to share our insights into the latest developments within this relatively new area of UAS. You can find video demonstrations, news and more background information online at www.gim-international.com. Happy reading!

Photography: Arie Bruinsma

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The front cover of this extra issue of *GIM International* shows a UAV being launched by hand. Spanish company Hábitat Estudios Ambientales S.L. has developed unmanned aerial platforms for aerial imaging, multispectral and photogrammetry services. With this special issue dedicated to UAS, *GIM International* recognises the importance of UAS technology, the development of which Christian Heipke (see interview) also regards as very positive for the geomatics community.

(PHOTO COURTESY: HÁBITAT ESTUDIOS AMBIENTALES S.L.)

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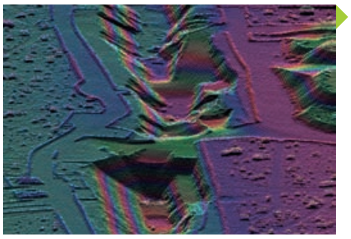

Peaceful Use of Drones

Unmanned Aerial Systems (UAS) – known by the wider public as 'drones' mainly in a military context – have proven their suitability for a broad range of peaceful geo-related tasks such as mapping of hazard-prone areas, flood prevention and road safety. I am not aware of any other geomatics technology that has become as popular among so many surveyors in such a short time as UAS. Why are so many professionals so impressed? What surveyors value most is the

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ability to revisit sites so easily. The same scene can be captured over and over again, whether every other day, every week, every month or as often the task requires. Revisits allow rapid monitoring of dikes, dunes, landslides, construction sites, open-pit mines, crops, floods and many other man-made objects, land uses and events. And the location of the site is irrelevant – whether it is located below sea level, in dusty deserts or high in the mountains, UAS can handle the job. Some field surveyors have to operate in quarries and mines, walking over piles of harmful waste or placing their rods while surrounded by roaring heavy machinery. A UAS relieves them of visiting such hazardous settings in person, thus avoiding potential accidents and health risks. Add to this the low cost of purchase and operation as well as the ease of use without compromising accuracy, and the surveyors' zeal becomes understandable. Indeed, the accuracy achievable using UAS is similar to that of images captured in conventional surveying, either with both feet firmly on the ground or by a camera on board a manned aircraft high in the sky.

The carriers can be split up into two broad groups: fixed wings and multicopters. Both are easily portable but fixed wings can stay airborne for longer, can resist higher wind forces and capture larger sites per flight. Multicopters are better manoeuvrable and need only small launch and landing spaces. The rapid rise and growing popularity of the UAS ensued from a once-in-a-decade convergence of lucky coincidences. Micro-electronics, auto-piloting, high-capacity batteries, super materials that are strong yet lightweight, wireless communication, compact digital cameras, image-processing software, miniaturisation of GNSS and INS, and so on and so forth – all of these novelties reinforced each other and everything fell into place. Today's photogrammetric software supports high automation of the entire chain, from flight planning, accurate calibration of consumer cameras and aero-triangulation up to the creation of DEMs and orthomosaics as well as their confluence: 3D virtual landscapes in which a surveyor can place a cursor, as if it were a rod, over a terrain point from the comfort of the office. Field survey is only necessary when high-precision georeferencing is required, and it is done by measuring through DGNSS the coordinates at sub-centimetre level of around half a dozen ground control points evenly distributed along the borders of the site. The full survey, from flight planning up to the final products, can be conducted in just one or two days.

All of the above sounds wonderful, doesn't it? Are there any snags? Launch and flight are subject to the same mandatory regulations as for manned aircraft: permits have to be granted no matter how small the plane or copter is. However, the US and Europe are working on rules to open their skies to UAS for civilian tasks by 2015 and 2016, respectively. Another hitch is the mistrust of citizens and feelings of discomfort about government intrusion into private lives: 'Big Brother is watching you'. It is true: most geomatics technologies have been initially developed for military purposes. But history has shown that what can be used for violence can also be used for the greater good. Organisations such as ISPRS and FIG could play a major part in creating awareness of the huge potential the peaceful use of drones offers by addressing the general public, decision-makers and politicians alike.

GIM INTERNATIONAL INTERVIEWS CHRISTIAN HEIPKE

UAS: Filling the Gap

The International Society for Photogrammetry and Remote Sensing (ISPRS) is one of the leading organisations within the geomatics sector and has a long-standing partnership with *GIM International*. We spoke to Christian Heipke, secretary general of the ISPRS, and asked him to share his views on the growing role of unmanned aerial systems (UAS), a major development in data acquisition at the moment. Christian Heipke is also member of the Scientific Committee of UAV-g 2013 in Rostock, Germany, a conference which focuses on unmanned aerial vehicles in geomatics.

One of the most recent major developments in photogrammetry is the rise of unmanned aerial systems. What do you think of the all the exposure that UAS are receiving these days?

I believe that the development of UAS is very positive for our community: first of all, it increases the possibilities for remotely capturing data – image sequences, laser scanning data, temperatures, gas concentration, etc. – and thus gives people who employ this technology professionally a competitive advantage. Secondly, when you have control over the complete sequence of acquiring, processing and distributing geospatial information, you have more confidence in this technology, especially if you are not a geomatics specialist. Also, UAS enjoy considerable media coverage which helps our industry. And finally, there is a fun aspect to UAS – people like playing around with such devices, which again gives our industry a positive image, and may even help to attract more students to our field.

Which geo-related applications are likely to benefit most from using UAS?

As a platform, the type of UAS we are talking about in photogrammetry closes the gap between terrestrial and aerial imaging. A UAS is much easier to employ than aircraft, and at least for small projects it is much more economical. Possible applications include archaeology, precision farming and mapping small areas in general. If monitoring is part of the job and the area needs to be revised frequently, for instance in construction site documentation or when monitoring traffic jams or sporting events, this is of course an added bonus. One can also envision a UAS being equipped with a thermal camera to detect heat leakages in industrial plants. In disaster management, of course, rescue crews can benefit from using UAS to quickly obtain an overview of the situation, and security applications also profit from UAS.

What will be the role of UAS for modelling the built environment in 3D?

Since the built environment is of course an area where much change happens, monitoring is a major task. UAS can be used for checking if a database of the neighbourhood is complete and up to date by comparing its content to UAS images, or for acquiring newly constructed buildings, annexes, etc. As mentioned before, oblique images taken from a UAS can also be used to render the 3D city model for visualisation purposes.

Are there any major obstacles blocking the path to UAS becoming an established photogrammetric technology?

In terms of technology, power is one of the most limiting factors today. Batteries are very heavy, thus UAS can only stay in the air for a relatively short amount of time. For rotary wing UAS such as quadcopters and octocopters as well as for some fixed wing systems, wind and weather can be another limiting factor – flying in rough meteorological conditions is not advisable. On the non-technical side, flight permits are sometimes hard to obtain for safety reasons, and data privacy may become an issue, as was the case with Google Street View in a number of countries. But with proper planning, these issues should not be a real obstacle for photogrammetric projects.

Legislation is an issue when it comes to wider implementation of UAS in the geomatics sector. Which developments do you foresee in terms of the legal aspect?

I see two issues here: data privacy and technical safety. As far as data privacy is concerned, we need clear regulations, preferably not only on the national level, which state under which circumstances the use of a UAS is allowed. One way to increase public acceptance might be to enable people who feel they are being observed by a passing UAS to make contact with the UAS. They could for instance send a message from their mobile phone to learn what type of data the UAS is currently capturing. They could also ask to have an online video stream transmitted to their local device, ▶

Christian Heipke

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so that they can check whether or not their privacy is being infringed upon. Such two-way communication with an unknown UAS might seem unrealistic, but today's technology makes it feasible. As far as safety is concerned, we need to develop the systems to a level that accidents will become very unlikely. Air traffic control can serve as a role model in this regard. We must realise, of course, that accidents will still happen – just as they do in manned air traffic. The challenge is to make UAS safe enough that the level of risk becomes acceptable.

The spatial resolution of today's satellite imagery is 41cm, although this figure is effectively 50cm due to the US government's restrictions on civilian imaging. The trend is towards increasingly higher resolution. Will such imagery eventually become a competitor for aerial photogrammetry?

The answer is a clear yes. At a ground resolution of 50cm, we already see severe competition. Of course, celestial mechanics can't be beaten – the satellites must follow their orbits. Hence, today, images from space cannot be acquired with the same flexibility as those from the air. But this situation may change once we have access to satellite constellations, and these have started to appear in recent years. RapidEye with five satellites in medium resolution and the French Pléiades system with two high-resolution satellites are only the first two examples.

On the other hand, there is a clear demand for even higher ground resolution for many applications. Many of the aerial images acquired today have a pixel size on the ground of 10cm or less. Thus, it seems that there will still be a market for both satellite and aerial imagery in the foreseeable future.

UAS can operate autonomously as a result of digital flightplans, while today's software enables automatic generation of digital elevation models and orthoimagery. How do conventional DPWs need to be adapted in order to become UAS software?

Most DPW software is optimised with respect to aerial image blocks with parallel viewing direction and regular overlap in and across the flight direction. However, UAS produce many more and often smaller images with rather varying exterior orientation and irregular overlap, and the viewing direction may be oblique or nadir. In order to handle such images, DPW software must become more flexible and more robust – this also goes for input formats, but primarily for automatic generation of approximate values to run matching and bundle adjustment processes, and for a proper consideration of distortion during image exploitation. Furthermore, manual inspection of oblique images is a necessity. Finally, due to the many images, a free and smooth roaming across different stereo models without operator intervention is a must.

Which major developments do you foresee, in geodata acquisition technology in general and in photogrammetry specifically, in the next five years?

I guess what we will see is an even closer integration between methodologies from aerial and close-range photogrammetry – UAVs and oblique images are just two examples of this trend. We will also see a further integration of different sensors (optical and thermal cameras, laser scanners, etc.) to form geosensor networks and platforms for mobile mapping and robotics applications. On a more general note, crowdsourcing and community mapping are very interesting alternatives to traditional data acquisition.

On the processing side, we will see more and more automation for vector data acquisition, updates and monitoring. Sensor orientation, surface matching and orthophoto generation are automated already, and classification and image interpretation will follow in the

future. The need is partly due to the sheer amount of data being acquired every day; think of the many satellites in orbit, and how many millions of images are being uploaded to the web every day. Automation is the only way to process this increasing volume of images. Real-time processing is another trend which will become more important. I already mentioned obstacle avoidance, which by the way is also important in UAS campaigns, but many monitoring tasks demand fast results as well. Geoinformation for personal use such as pedestrian navigation and personalised location-based services are another driving force in our field. All these trends are of course governed by the development of the internet, and standardisation and ubiquitous computing will become increasingly important.

UAS have been called a hype by some people in the geomatics industry. Were these people too sceptical, and should they now admit that the UAS revolution has begun?

I believe more in evolution than in revolution. Like in many other fields, once a new and promising technology or trend emerges, there are always some people who believe it will solve all current problems. Of course, UAS do not, but they do have great potential to fill in the gap between aerial and terrestrial survey. At present, power supply and thus flying time is limited, UAS are sensitive to wind, and a number of legal issues await a solution (see above). But UAS are too good and too promising to be seriously hampered by these issues; they will find their way into practice as a complementary data acquisition technology in the geomatics field.

UAS will find their way into practice as a complementary data acquisition technology in the geomatics field

QUALITY MATTERS

Experiences in UAS Photogrammetry

UAS mapping is widely accepted as a new method for acquiring spatial image data. The main business opportunities clearly lie in projects which are too small to be of interest for aircraft and helicopter platforms and too big for field mapping. Nevertheless, performing UAS operations profitably and with high-quality results is quite demanding. At the end of the day, the paying end customer is not really interested in whether the data was produced using UAS or more traditional methods; data quality is all that matters. This article focuses on UAS mapping productivity topics, shedding light on the practical challenges of UAS operation and data processing.

Mikko Sippo is CEO of PIEneering in Helsinki, Finland, a company focusing on UAS photogrammetry software solutions since 2007. His varied career has included general management, sales, business development and project management roles.

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Today's Unmanned Aerial System (UAS) mapping market is divided into three main groups: UAS manufacturers, data-processing technology providers and aerial oper¬ators who fly the systems to meet the needs of paying end customers. While there are alliances between UAS manufacturers and processing technology providers, it is important to note that each of the three technological and service-providing roles require quite different know-how and operational processes (Figure 1).

A mapping UAS typically comprises the following components: unmanned aircraft with autopilot (fixed or rotating wing), mission planning and ground station software with radio link, camera and optionally a launch and landing control system for high-speed fixed wing systems (Figure 2). Photogrammetric software is used to process the acquired images into data products, orthomosaics and 3D point clouds so that they are ready for use in GIS and planning systems.

PERFORMANCE FACTORS

A UAS is a decisive working instrument for an operator, which in terms of investment is comparable to a robot tachymeter or a terrestrial laser scanner system. There are number of commercials systems to choose from. When planning a system purchase, the component which has by far the greatest effect on the end product results is the on-board camera. Nowadays, options range from high-performance and lightweight full frame (35mm) consumer cameras to metric cameras specifically built for UAS applications. Another fundamental choice is whether to select a rotary or fixed wing device. Fixed wing vehicles usually fly faster and are capable of covering larger areas of interest. Meanwhile, rotating wing systems typically have lower cruising speeds but are capable of operating in limited spaces and in urban areas without problems.

There are a number of design features which have a direct impact on operational performance and thus on the productivity of a UAS. Since the system should be suitable for one-person operation in order to typically reduce operating costs

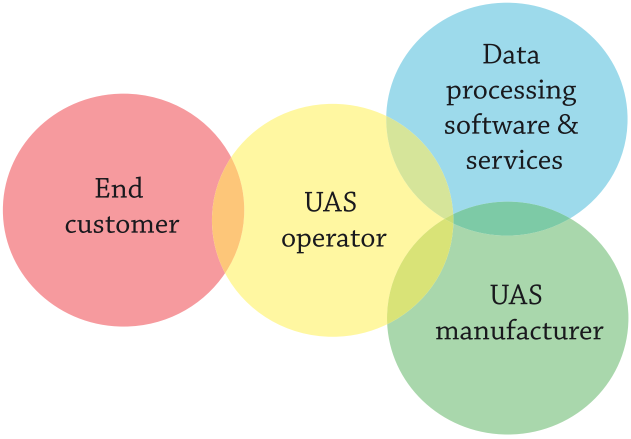


Figure 1, Stakeholders in the UAS mapping market.

Figure 2, A typical UAS (Image courtesy: C-Astral).

by half, system design is being forced towards simplicity. Moreover, operators should be able to control a UAS manually in the air – not only to comply with legal requirements by the relevant authorities, but also as an important safety feature in the case of unexpected mechanical failure or air traffic.

A mapping mission using lightweight systems can be started with a manual toss whereas heavier systems need a launcher system – a trade-off between operation simplicity and added hardware enabling larger areal capacity. Lighter system cans usually be landed manually into a small space. Meanwhile, a heavier system should have an option for parachute landing; to land a UAS on its belly may require quite a lot of open space, which cannot always be provided, and expose the sensitive camera to repeated bumps and shocks during landings.

PRODUCTIVITY

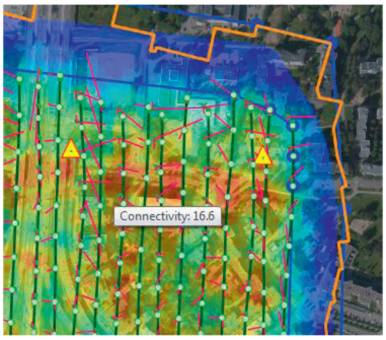
With regard to productivity, the most critical component is the auto pilot and its control software. The software should make it possible to simultaneously plan larger area missions which can be covered with multiple, overlapping flights. The shape of an area of interest should be freely defined. For example, a mapping mission stretching over a corridor several kilometres long may be possible in just one flight, or it may require splitting the area into multiple flights over a series of rectangular areas. This means an operator may have to spend significantly more time at the site and complete a mission in many different weather conditions and types of light.

There are differences in the way of optimising flying patterns and turns, and this has a direct influence on effective flying times. Finally, by controlling camera triggering based on the advanced ground distance rather than on a constant time interval, it is possible to eliminate the effects of head/tails wind on the image overlaps.

An operator usually prepares a UAS mission in the office before travelling to the site. Air space restrictions and obstacles should be checked in advance, and the flight patterns covering the areas of interest should be prepared using mission-planning software. The actual flights can be conducted when weather conditions allow: not too much wind, not too much rain, and sufficient light for the camera to operate at a short shutter speed. An operator should also have software for checking the captured data in the field, in order to monitor whether the right area is being covered, the image quality is satisfactory and the image overlaps appear as planned.

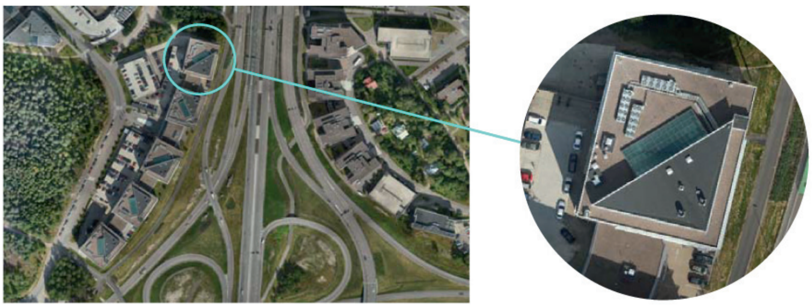
DATA PROCESSING OPTIONS

There is a clear need for two different data processing options: one for producing quick mosaics with so-called GIS accuracy and another to generate high-precision results for the more demanding surveying industry. It is the latter which is the obvious target group for PIEneering. Mosaic solutions serve multiple end customer requirements, in many ways representing the vast business potential of UAS mapping applications outside



▲ *Figure 3, Example of graphical quality reporting.*

▲ *Automatically generated DSM (10cm GSD) from a UAS mission.*



◀ *Automatically generated true orthomosaic from a UAS mission.*

of the traditional photogrammetry industry. Software solutions for this field need to produce results quickly and automatically. Completeness and spatial accuracy of the end result is typically only a secondary consideration for end customers, and geometrical faults may be visible, especially in forested and built-up areas.

In contrast, the surveying industry is accustomed to serving professional customers who require controlled quality assurance and error propagation. There are two aspects of quality affecting the output: accuracy and reliability. Accuracy describes the compatibility of the output with respect to any reference frame, such as the control points. Reliability refers to how sensitive the output is to system errors, such as uncompensated image deformations, blunders, etc.

EXPRESSING QUALITY

But how can quality be expressed to the end customer? Traditionally, a number of statistical quality indicators are used, such as residuals, variance components, etc., documented with alphanumeric listings. The problem is that relatively few people can interpret such statistics effectively. A more intuitive way to communicate quality is to use graphics extensively, along with numeric data (Figure 3). It should be possible for a survey professional to assess the quality level without needing a degree in photogrammetry.

The most common reservations about UAS photogrammetry tend to focus on accuracy issues. Quality reporting enables an operator to demonstrate the quality of the delivered data. Hence, the project acceptance criteria can be set implicitly, and everyone is assured of getting their bills paid. There are particular challenges related to UAS data-processing software performance. A rather unstable UAS platform generates image blocks of varying image quality, including significant differences in image scale and image tilts and inaccurate initial camera orientation and exposure location data.
As a consequence, processing UAS data is more demanding than processing traditional aircraft blocks. To get the job done, UAS blocks therefore require powerful software com¬bining the best image engi¬neering al¬gorithms of photogrammetry and machine vision.

When camera performance allows, it is preferable to capture images in RAW format instead of common JPEG. RAW images offer improved resolution power and accuracy by storing thousands of grey shades per pixel instead of the JPEG range of 0-255. However, processing UAS blocks tends to take time. One practical solution is to exploit powerful but cheap gaming graphic cards (GPUs) in a PC, thus increasing the processing speed by a factor of 20-50 per installed card.

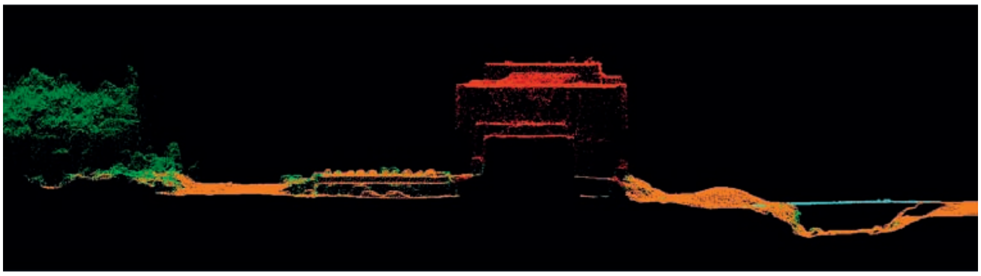


Figure 4, A cross section derived from a classified point cloud.

3D model of an open pit.

Detailed 3D point clouds seem to be of particular interest to end customers, since the data can be used for numerous volume calculation applications and for generating true orthomosaics. End customers are quite often interested in more refined data output, such as 'bald earth' surfaces or classified data layers derived from a DSM. Point cloud and DTM management software, such as Terrasolid's Terrascan, can be used for this, for cross-sectioning and visualisation purposes for example (Figure 4).

Today, a UAS operator can choose between licensed software and cloud services as data processing options. Choices are welcome, as customers' needs vary – it is sensible for operators with less knowledge of photogrammetry to rely on services, while it is natural for professional photogrammetrists to choose the software option. In either case, UAS data processing software, or services, must provide automatic operation, the capability to meet the challenges of UAS-specific blocks, provide a means for controlled quality, and be capable of rapidly processing thousands of images.

DATA ACCURACY

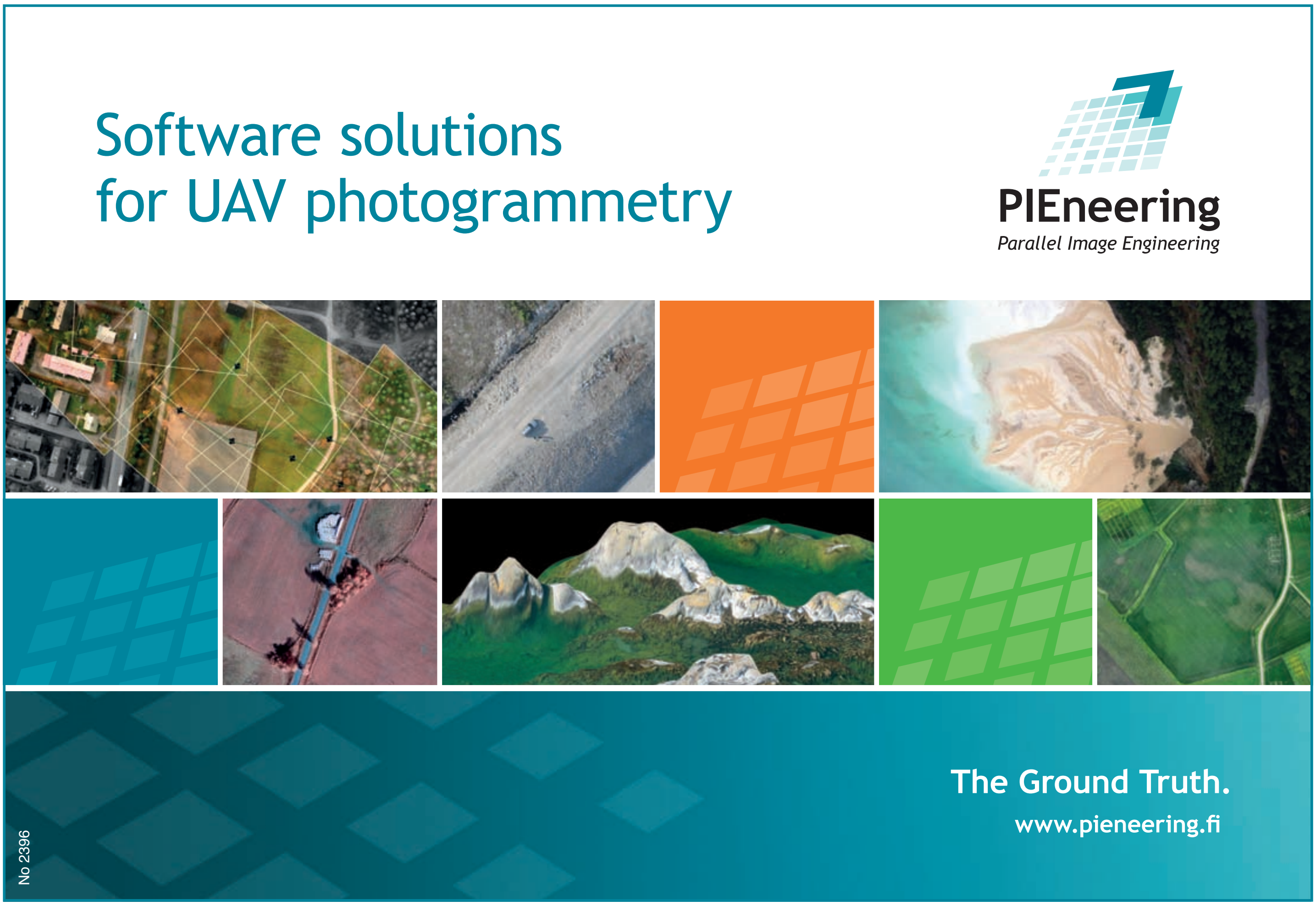
There are four main aspects which have the greatest influence on data accuracy: the number of ground control points, consistency of the photogrammetric block, image quality and camera optics. When GCPs cover the target area and are spread evenly, absolute accuracy over the target area can be controlled. Adequate image overlaps (70/70%) compensate for the instability of the UAS as an imaging platform and make the mathematical solution rigid. Once again, good image quality is essential. Consumer cameras are not built for metric operations, and the instability of the optics can cause varying deformation. Any deformation drastically reduces the accuracy and must be compensated with camera calibration, either with laboratory calibration or with self-calibration during data processing. With everything in place, it is possible to achieve absolute accuracy of 0.5 pixel GSD in XY direction and 1 pixel GSD in height with aerial triangulation. For more details, please refer to the white paper [1].

CONCLUSIONS

As a method for acquiring aerial image data, UAS mapping is capable of providing high-quality results for the professional survey industry. Quality does not come easily, but instead requires advanced hardware and software, skilled operators and carefully executed mapping missions. Controlling quality throughout the entire production process increases productivity, helps to strengthen confidence in the UAS mapping method, and promotes project sales.

MORE INFORMATION

1. www.pieneering.fi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TESTING SUITABILITY FOR BOUNDARY IDENTIFICATION IN URBAN AREAS

UAS for Cadastral Applications

When ownership of one or more parts of a parcel changes, seller(s) and buyer(s) are legally obliged to identify the new boundaries. Stakeholders are often unable to attend the on-site identification session. Could high-resolution images captured by UAS bring relief? Would it be possible to use a high-quality orthomosaic as substitute? The crux is that precision and spatial resolution must be high enough. Having conducted tests in an urbanised area in The Netherlands, the authors conclude that the precision of 3cm is similar to conventional land surveying and that UAS imagery enables seller(s) and buyer(s) to perform boundary identification.

Identification of the location of new legal boundaries is presently done on site in the presence of a cadastral officer. Even when an appointment has been made, and sometimes when the cadastral officer is already on site, seller and/or buyer frequently cancel the arrangement – an undesirable and costly phenomenon. To improve the efficiency of boundary identification, the simultaneous presence of stakeholders on site should be substituted by other means. High-resolution aerial imagery discloses the topographical situation and thus offers a potential alternative, provided that the precision is 6cm or better, since that is the precision of conventional land surveying.

CONCEPT

High-resolution images enable the creation of orthomosaics of uniform scale and hence the boundaries outlined are free of distortion. However, orthomosaics created from conventional aerial images are unsuitable because their current precision and resolution are too low. Improving this to the

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▸ *Figure 1, Falcon 8 (left) and Microdone MD-4 1000.*

▴ *Figure 2, Test at the Pyramid of Austerlitz (left) conducted by experts from KLPD, Kadaster and NLR.*

required level would be very costly. Images captured by Unmanned Aerial Systems (UAS) seem to have appropriate characteristics: flying at a relatively low altitude (40m) results in better resolutions while the precision is 6 to 10cm, as Swiss tests show. A slight improvement to these figures would be enough to make UAS imagery suitable for boundary identification. These images would eliminate the necessity for all stakeholders – seller(s), buyer(s) and cadastral officer – to be present on site simultaneously. Instead, the seller(s) and buyer(s) would be able to identify the new boundaries on the image, possibly at the moment of transaction in the notary office. The cadastral officer would then be able to sketch the boundary on a soft or hard copy of the aerial image.

TEST SET-UP

During the winter and spring of 2012, Kadaster started tests on the suitability of aerial images captured by UAS for the identification of property boundaries. The tests were conducted in co-operation with KLPD (Dutch national police force), National Aerospace Laboratory of the Netherlands (NLR) and, in a later stage, the firm OrbitGIS. Three experiments were conducted at two locations: Austerlitz and the city of Nunspeet. The first experiment carried out in Austerlitz concerned a learning phase aimed at getting acquainted with the technology. The second experiment concerned a practical case. The third experiment – also a practical case – was necessary due to some failures during the second experiment.

EQUIPMENT

A Falcon 8 from Ascending Technologies (AscTec) was used in the first and second experiments, and a Microdone MD-4 1000 Beta was used in the third experiment (Figure 1). The Falcon 8 is an octocopter (eight rotors), remains stable up to wind speeds of 10m/sec (5 Beaufort; fresh breeze), can carry a payload of 500g and can stay in air for 20 minutes. Navigation and positioning is done using GNSS, an inertial measurement unit (IMU), a barometric height sensor and a compass. The camera on board was a Panasonic LX-3, which is a good-quality compact camera with a focal length of 5.1mm and has an image size of 3,648 x 2,736 pixels and a pixel size of 2µm. The Microdone MD-4 1000 Beta is a quadrocopter (four rotors), can carry a payload of 1,200g and can stay in the air for up to 45 minutes. Navigation and positioning is done using GNSS. The camera on board was an Olympus E-P3 OGT with a focal length of 17mm, an image size of 4,032 x 3,024 pixels and a pixel size of 4.4µm. During the flights, the built-in stabilisation of the cameras was switched off since stabilisation shifts the lens, which infringes the calibration parameters. Since a UAS can only stay in the air for a limited time span, an aerial survey is usually divided into several sub-flights, depending on the area that has to be covered.

AUSTERLITZ

The Pyramid of Austerlitz, a victory monument built by Napoleon's army in 1804, is an unpopulated, sandy

▲ Figure 3, Improvements: targets for camera calibration are laid out in terrain and professional ground markers are used (inset).

▲ Figure 4, UAS in action above new homes in Nunspeet, April 2012.

area covered by a few buildings and surrounded by forest (Figure 2). The test area was chosen in order to gain experience while minimising the potential risk of injuring casual bystanders and passing public. First ground control points (GCP) were signalised and their positions measured with GNSS. The signals consisted of out-of-use compact discs as their silver sheen was thought to warrant good visibility in the images. Their visibility was indeed very good, although sometimes too good as some signals appeared as flares on the images due to high reflection. After a few test flights, the actual flights were started at around 13:00h. The temperature was around freezing, which caused battery failure. The UAS could stay in the air for less than 10 minutes instead of the nominal 20 minutes. At 15:00h, rainfall prompted cancellation of the last flight. This experiment improved insight into preparation of the flight plan, distribution of GCPs, setting of camera parameters and selection of proper software for block adjustment and orthomosaic creation. The camera was not calibrated. After block adjustment, the average precision was worse than 10cm.

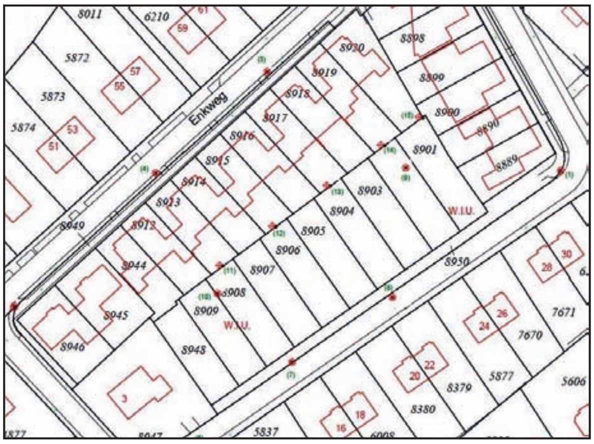
NUNSPEET

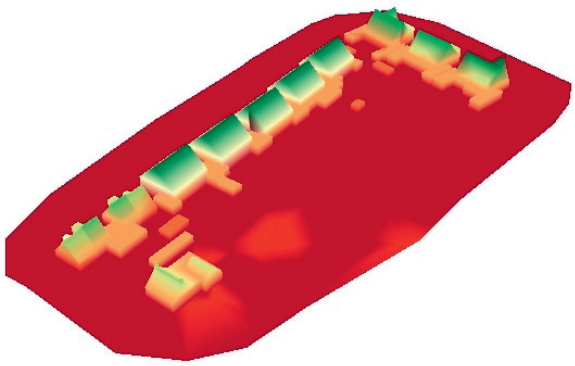
The second experiment, conducted in Nunspeet on 29 March 2012, concerned a real cadastral situation in which the parcel boundaries of 20 new houses had been identified and measured. Kadaster and its partners planned and executed four sub-flights to cover the target area, for which municipal permission was required since the flights would be conducted over houses and civilians. Instead of compact discs, professional ground markers were placed at distributed locations, and targets placed on paper sheets enabled self-calibration of the camera (Figure 3). The parameters were calculated during block adjustment. The last flight (Figure 4) could not be completed entirely since a sudden blast threw the UAS off balance and the experiment had to be terminated, resulting in incomplete coverage of the area. Camera calibration plus better visibility and distribution of GCPs resulted in an average precision of 3cm after block adjustment. Due to incomplete coverage, no useful orthomosaic could be generated.

THIRD EXPERIMENT

A third experiment was therefore set up and conducted on 19 June 2012, also in Nunspeet. In this experiment, the earlier experiences gained on specifying flight parameters and number and distribution of GCPs could be fully explored. Eight GCPs

▼ Figure 5, Cadastral map of Nunspeet showing the test area including the placement of ground markers (red circles) and location of sewer pits (red squares).





▲ Figure 6, Digital Elevation Model of the Nunspeet test site.

were well distributed along the border of the site and two GCPs were placed in the centre part (Figure 5). When conditions are optimal, the number of GCPs might be further reduced to 5 or 6. Just one flight, conducted within 25 minutes, sufficed to capture the site with 80% overlap both across and

along track from an altitude of 58m, yielding 360 images. Compared to multiple flights, which capture a site in bits and pieces, complete coverage carried out in one flight results in higher geometrical fidelity. Nevertheless, to increase redundancy, a second flight was performed yielding 380 images. Tie points were automatically detected using image matching software. The block adjustment revealed a precision of 3cm. Next, a Digital Elevation Model (DEM) was created using OrbitGIS software (Figure 6), and a quasi 'true' orthomosaic was generated with the same software. Projection of property boundaries onto the orthomosaic showed that orthomosaics can be created with a precision of 2 to 3cm (Figure 7).

FINAL REMARKS

These tests show that low-altitude aerial imagery is suitable for boundary identification. However, the conditions for which the method is feasible need further investigation; for example, UAS might become the preferred method for inaccessible areas. GCPs were signalised and measured prior to flight, but in an operational setting this task might be performed more optimally after image capture. Of course, a prerequisite is that all stakeholders – buyer(s), seller(s) and cadastral officers – should adopt the method and get used to it. Furthermore, the legal consequences have to be scrutinised.

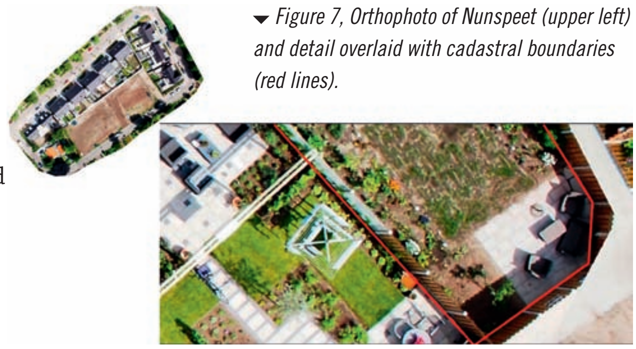


Figure 7, Orthophoto of Nunspeet (upper left) and detail overlaid with cadastral boundaries (red lines).

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ACCURACY ASSESSMENT, TIME SAVINGS AND SAFETY

UAS for Mining

How long does the throughput of a UAS survey take, from flight to final products? What is the accuracy of the volume calculated from the digital surface model? How can a UAS contribute to the safety of surveyors? The authors discuss these and other issues, focusing on the experiences gained by Global Vision, a company based in South Africa that offers UAS services to mining sites in South Africa and Namibia.

Global Vision developed its own multicopter in-house (Figure 1). The pre-programmable tri-rotor copter with six propellers is equipped with a DJI auto-pilot system and a 24-megapixel camera. An on-board GNSS provides estimates of the image positions, which are transmitted in real time – through a 900MHz data link – to a ground laptop set up at a base in a safe zone of the mine (Figure 2). As the UAS flies over the site, it acquires thousands of images. The operator does not require special skills; the lightweight copter automatically takes off, captures images in a grid pattern and safely lands back at its starting point. If any malfunction should occur, the UAS is programmed to fly back or land.

Craig Vorster, director of Global Vision, completed numerous computer courses and worked in the family business of hobby shops, particularly enjoying the radio-controlled disciplines. This led to the idea of combining the radio-controlled multi-rotor flying platform with Pix4uav to provide the mining industry with a cost-effective aerial surveying tool. Currently he mainly focuses on processing aerial images.

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Christoph Strecha received a PhD degree from the Catholic University of Leuven (Belgium) in 2008 under the supervision of prof Luc Van Gool for his thesis on multi-view stereo. He then worked as a post-doc and was co-chair of ISPRS Commission III/1. In 2011 he founded Pix4D, a Swiss company which develops and markets software for fully automatic production of orthomosaics and 3D models from aerial and UAV images.

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PIX4D

After flight, the images are processed by the Pix4D photogrammetric package. First the interior and exterior orientation parameters have to be determined by bundle block adjustment (BBA). Next, digital surface models (DSMs), orthomosaics and products derived from these are generated. The core of the package consists of image matching modules which are based on the achievements of computer vision research. From the contrast information present in a region around a point, the values of features are computed using a new computer vision-based approach. To find the conjugate point in an overlapping image, the features of the target point in the one image are compared with those of candidate points in the overlap of the other image. In the BBA process of traditional photogrammetry, about 20 keypoints per image are selected;

Figure 1, The tri-rotor copter with six propellers was developed in-house.

Figure 2, The UAS base was set up at a safe spot in the mine.

in Pix4D this number is over 60,000. Determination of subpixel location of keypoints, calculation of their descriptors and comparison between all of them can be done extremely fast. Next, the interior orientation parameters – focal length, principal point and lens distortions – and exterior orientation parameters – position of the camera's projection centre and attitude of the image plane – are iteratively calculated. When several thousand points are matched across overlaps, millions of variables are optimised and focal length, lens distortions and other interior orientation parameters of consumer-grade non-metric cameras can be accurately computed, resulting in survey-grade accuracy. The initial georeferencing based on on-board GNSS measurements is refined by including Ground Control Points (GCPs). After finalising BBA, Pix4D generates 3D coordinates of points up to each pixel of each image by optimising and cross-correlating image content. This extremely dense cloud of points is then filtered and interpolated, leading to DSMs. Of course, Pix4D also generates orthoimages and derived products such as volumes.

NOOITGEDACHT MINE

Global Vision adopted Pix4D in January 2013 and its abilities were examined by capturing the 66ha of the Nooitgedacht mine, which is located 10km outside the small town of Northam in Limpopo, South Africa (Figure 3). This narrow open-cast chrome mine is currently being exploited by Andru Mining. During the aerial survey, 721 images were taken with a GSD of 2.24cm, an along-track overlap of 80% and an across-track overlap of 40%. It took 160 minutes on a standard desktop PC to extract over 6.3 million keypoints, to calculate the values of their features and their subpixel location and to assign to every keypoint its conjugates in the overlaps. This step resulted in 2.4 million 3D points suitable for BBA. The Root Mean Square Error

Figure 3, Orthomosaic of the Nooitgedacht chrome mine.


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(RMSE) after BBA was 0.16 pixel or 0.4cm. To create a high-density DSM, 18 million points were extracted which took about 250 minutes. These points were automatically filtered and interpolated to generate a DSM consisting of 6 million points with a GSD of 2.24cm. The generation of the orthomosaic by combining the original images with the DSM took about 240 minutes (Figure 4). These outputs were used to generate reports on volume, mine planning, mine rehabilitation and other valuable mining information.

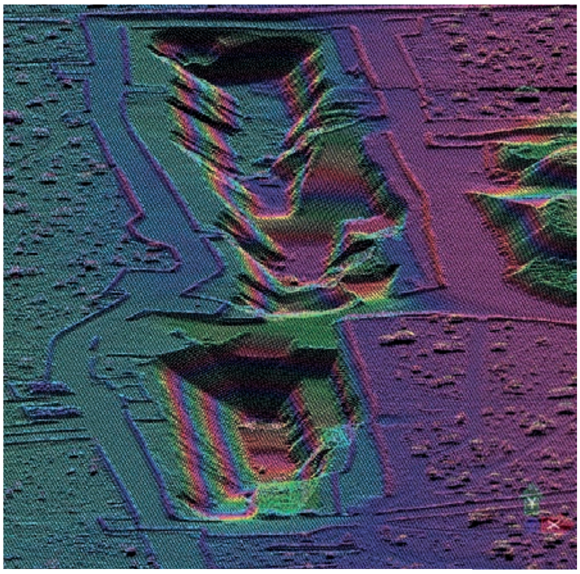
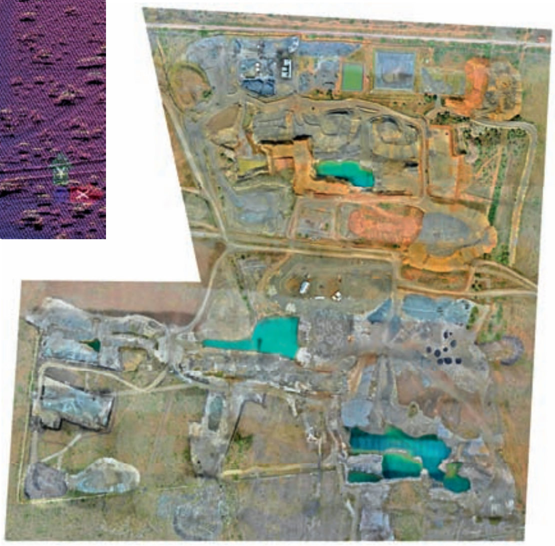


Figure 4, Digital surface model of the Nooitgedacht mine.

Figure 5, Orthomosaic of the Ruukki SA Stellite mining site.



ACCURACY ASSESSMENT

For accurate georeferencing purposes, 7 GCPs were measured by GNSS along the borders of the Nooitgedacht site. Five GCPs were used in the BBA procedure and two for verification purposes. After BBA, the residuals of the 5 GCPs appeared to be less than 1cm, with an RMSE of 0.83cm. Comparison of the coordinates of the two verification GCPs with those computed from the images revealed an RMSE of 4.8cm in height and 2.5cm in planimetry. That is less than twice the GSD, thus demonstrating the robustness of the BBA on consumer-grade cameras.
For assessing UAS DSM accuracy, a ground truth dataset of 3,500 grid points with spacing of 10m was collected by RTK GNSS across the Nooitgedacht mine. Comparison of the heights of individual points of the GNSS DSM with the heights at the same location in the UAS DSM revealed an RMSE of 4.9cm, which is a similar value to the 4.8cm obtained from the verification GCPs mentioned earlier, thus validating the accuracy of the DSM generation. Using Bentley InRoads, the volumes of the UAS DSM and the GNSS DSM were computed and the difference was within 5%. Without doubt, the accuracy of individual GNSS points is higher than the accuracy of UAS points. However, the number of height points in the UAS DSM is nearly 2,000 times larger than the number in the GNSS DSM. A spacing of a few centimetres instead of 10 metres can cope very well with surface fluctuations especially when shapes are complex.
The much higher density of the UAS DSM results in a higher accuracy of volume computation even when the reported accuracy of the individual heights is lower.

TIME SAVINGS

Ruukki SA is a South African chrome producer. To assess time and thus cost savings, the UAS survey of one of its open-pit mines was examined (Figure 5). The 2.5km^2 site has been surveyed many times by conventional means. A team consisting of two to four surveyors needs between 7 and 10 days of field work to collect 3D coordinates of terrain points on a 10m grid using GNSS rovers. The in-office post-processing of the points collected takes one to three days. With a UAS, the same area could be captured in one day by one operator carrying one UAS and one GNSS rover for collecting 10 to 20 GCPs along the border of the site. Processing of the 2,611 images – 99% of which is done automatically – and the generation of end products require one to four days depending on the number of photos to be processed and on the type of report required. Final reports are thus delivered up to four times faster requiring 3 times less workforce. This efficiency leap enables cost-cutting of up to 80%.

SAFETY

When surveyors walk over a site to capture 3D coordinates of terrain points, they may have to venture into unsafe spots such as the very edge of high walls or the top of stockpiles and dumps. The use of a UAS increases safety since the surveyor does not need to go into hazardous areas, plus today's UAS are also very safe to operate.

FURTHER READING

Küng, O., 2012, Enabling UAV-based 3D mapping, *GIM International*, 26(7), http://bit.ly/12XTFI4

MORE INFORMATION

www.global-vision.co.za
www.pix4d.com

FROM TRIPODS AND TRUCKS TO VIRTUAL SURVEYING

UAS as a Tool for Surveyors

Since 2011, the use of Unmanned Aerial Systems (UAS) as complementary surveying devices has mushroomed. With resolutions as high as 1cm, the resulting imagery enables the highly automated production of detailed elevation data, orthophotos and 3D virtual landscapes. However, the gains in efficiency during data acquisition are accompanied by data management challenges and processing efforts which surveyors often underestimate. Here, the authors demonstrate how surveyors can make UAS technology economically feasible by balancing massive data volumes without compromising the quality of feature extraction.

The field surveyor intelligently selects lines and points to correctly and economically capture terrain features in three dimensions. His main task is to balance level of detail (or number of points) and quality. Choosing too many points adds to costs, yet too few points will impede completeness and accuracy. Finding the proper balance relies on the human capacity to analyse the terrain while standing in the midst of it. Field surveys directly result in vector data: point features such as lamp posts or property corners, line features such as tops of ditches or centres of roads, and polygons such as property parcels and lakes. Vector data requires minimal post-processing in the office to obtain the specified end product; the field work itself is the most labour-intensive part.

VIRTUAL SURVEYING

UAS surveys do not directly produce vector data. The survey starts with flight planning and aerial survey, resulting in digital images which cover the selected area at approximately equal resolution. Unlike with field surveys, no lines and points are captured during an aerial survey. Instead, this job has to be conducted in the office afterwards using orthophotos and Digital Elevation Models (DEM), both of which can be generated

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Walter Volkmann is a land surveyor with roots in Southern Africa. He is the founder and CEO of Micro Aerial Projects LLC in the US, and currently consults to the Kassel-based UAV manufacturer Aibotix GmbH on geospatial applications of UAV-based mapping operations.

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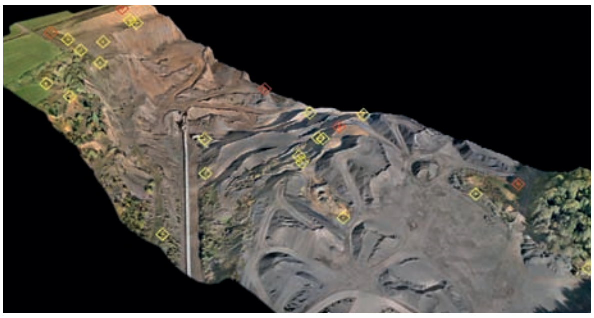
automatically using the proper software.

A typical ground sampling distance (GSD) of a few centimetres results in massive data volumes even when the area to be covered is just a few hectares. For example, a GSD of 2cm results in 2,500 pixels per square metre, which is equivalent to 25 million pixels per hectare. The challenge is to balance data volume with efficiency in feature extraction without loss of quality. Virtual surveying is a solution to this challenge. An easy-to-learn user interface allows intelligent, efficient and accurate feature extraction from realistic visualisations of topographic data (Figure 1).

▲ *Figure 1, 3D representation of a quarry generated by draping an orthophoto over a DEM.*



▲ *Figure 2, GCPs (red) and check points (yellow) distributed over a quarry.*

SURVEYING IN THE MODEL

Virtual surveying is done in a 3D model which resembles the actual terrain. The surveyor can navigate through the model and measure points by clicking the mouse, just as if he were placing a survey rod over a terrain point. A virtual environment shows the orthophoto draped over the DEM and enables the landscape to be viewed from many different viewpoints. The combination of orthophoto and DEM offers many advantages compared to 'heads-up' digitisation of orthophotos alone. The viewpoint can be easily changed to obtain an optimum perspective of the feature of interest, and zooming and roaming enables terrain features to be interpreted reliably and measured accurately. The surveyor can easily move around or jump over houses, trees, hedges and other obstructions. Furthermore, the 3D representation enables much easier detection of features than the conventional photogrammetric approach. The result is a better and more efficient identification and measurement of features compared to field surveying or conventional photogrammetry.

ACCURACY

UAS workflows have many steps, and each step contributes to the error budget of the end product. Consequently, quality assessment is rather complex. This can be illustrated by the accuracy assessment of a model of a 16.5ha quarry located near Kassel, Germany, for example. This was generated from 330 images with GSDs varying between 2cm at the top and 4cm at the bottom of the quarry (Figure 2). The red points represent Ground Control Points (GCP) for georeferencing to WGS 84 UTM. The 20 yellow points represent check points. Their 3D coordinates (E, N, H) were determined with RTK GNSS (accuracy better than 2cm) in the field and through virtual surveying. The resulting root-mean-square errors of the differences are: RMSE E = 4.8cm, RMSE N = 2.7cm and RMSE H = 5.5cm. A proper overall quality measure of the planar coordinates E and N – if at least 20 check points are available – is the Approximate Circular Error at 95% confidence level as defined in the *Manual of Photogrammetry*, Fifth Edition, ASPRS, pages 991-992 : ACE(95%) = 2.4477*0.5*(RMSE E + RMSE N). Given the above RMSE, ACE(95%) becomes 9.2cm and the vertical accuracy at 95% confidence level (1.96*RMSE H) becomes 10.8cm. Given a maximum GSD of 4cm in this project, these results confirm the rule of thumb that planimetric and vertical accuracies are of the order of two and three pixels respectively. In addition to the two overall quality measures outlined above, vector plots were drawn to enable detection of systematic errors which may indicate weaknesses in the adjustment. Figure 3 shows that the orientation of the errors in the left part differs from the

▼ *Figure 3, Horizontal error vectors (left) shown in yellow and vertical error vectors (green: positive; red: negative) at check points superimposed on an orthophoto and scaled by a factor of 1,000.*

◂ Figure 4, Two profiles: red was measured in the field, green by virtual surveying.

▴ Figure 5, Designing a noise barrier in a virtual landscape.

right part, suggesting that the use of more GCPs would improve the result.

SURVEY QUALITY

The above method of accuracy assessment is based on comparing measured points with check points, and it is commonly used by field surveyors who traditionally aim at high point accuracy. However, such an assessment disregards the benefits of aggregating many points with lesser accuracy to represent lines or surfaces. In Figure 4, the red profile is based on connecting distinct points measured by a surveyor in the terrain; the distance between consecutive points is large. The green profile is generated by virtual surveying which enables points to be collected at small intervals, thus yielding a better representation of the terrain shape. The accuracy of the individual points of the green profile is less than those of the red profile, but because there are so many of them, the quality of representation of the actual terrain feature of interest, i.e. the profile, is better.

DESIGNING CONSTRUCTION WORKS

UAS surveys are usually limited to 'as built' or 'as is' mapping projects. To be useful for staking out property corners and other demarcation tasks, the payload capacities and navigation accuracy of UAS needs improvement. This does not mean that UAS would always be unfit for designing construction works. Generally UAS is suitable for any project where data density prevails over accuracy. An example where UAS was successfully applied for design purposes was when capturing a motorway interchange in Belgium as part of a project to design a noise barrier. A Sirius drone from MAVinci was used to obtain aerial images with GSD 4cm and overlap 80% at a flying height of 140m. The images were georeferenced using 10 GCPs which were measured by RTK GNSS with an accuracy of 1cm, thus enabling the generation of a 3D model with 10cm accuracy in which the noise barriers could then be designed (Figure 5). Another successful design project was the acquisition of stereo imagery with GSD 1cm and 70% overlap covering a 250m trajectory of urban street for repair purposes using a VTOL (Aibot X6 from Aibotix). The images were acquired at a flying height of 50m and with a distance of 5m between successive exposure positions (Figure 6). One surveyor could perform the planning and air survey in less than two hours. Using around 120 images, processing was completed overnight so that the entire project could be finalised within 24 hours. Figure 7 shows a detail of the features measured in the virtual model, a task which would require a field crew of three individuals.

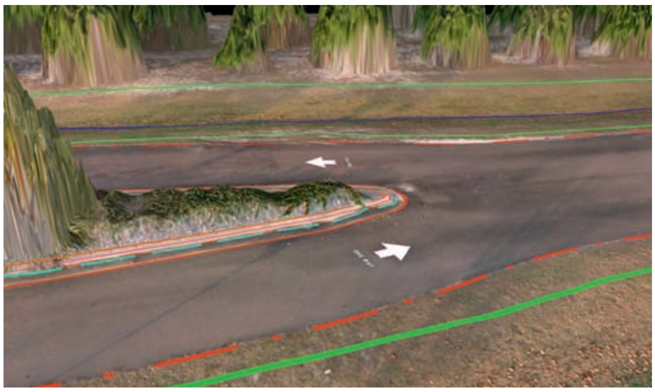
BENEFITS

Not all surveying projects are suitable for virtual surveying, but for those which are the benefits include: cost savings, since feature extraction in the 3D model can be done much faster than in the real world; surveying is not hindered by logistics or weather conditions; and no revisits to the terrain are necessary, since the virtual world can be quickly uploaded in case of mistakes or omissions. It is also the safest way to acquire data under harsh conditions such as in mine pits, along unstable slopes or in road traffic. Furthermore, virtual surveying improves productivity, resulting in increased turnover.

CONCLUDING REMARKS

As with any new technique, UAS requires investments in equipment, software and time to climb the learning curve. However, the level of investment can be modest – the investment in software and training is less than 10% of an averagely priced UAS. Hence, apart from the initial purchase of the UAS, the financial burden is bearable. Surveyors will continue to measure point, line and area features and to apply their expertise – only now not merely in the real world but also in the virtual world. ◂

▴ Figure 6, Urban street: yellow lines indicate the position of the camera's projection centres.



▴ Figure 7, Road features extracted in a virtual model.

Special UAS Issue of *GIM International*

In January 2013, we started a series on Unmanned Aerial Systems (UAS). The series became a huge success – we had never before received so many suggestions for potential articles for our magazine. As a result, and in view of the rise of UAS in the geomatics sector, we decided to publish an extra edition of *GIM International* dedicated to UAS.

That special edition is now right in front of you, and hopefully you will enjoy reading it. Here at our desks in the editorial office, we're interested in your feedback. Does this first UAS issue deserve a follow-up? Would you like to see another edition next year? Please let us know your thoughts and opinions by contacting Wim van Wegen, editorial manager. You can reach him by e-mail: wim.van.wegen@geomares.nl.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