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UAS EDITION

UAS and Lidar

A Rapidly Evolving Amalgamation of Proven Technologies

INTEGRATING UAS AND MULTIBEAM ECHOSOUNDER DATA

MULTISPECTRAL AND THERMAL SENSORS ON UAVS

UAS APPLICATIONS IN THE AGRICULTURE SECTOR


PHASEONE
1:4
f = 50 mm

The cover shows an Aibot X6 hexacopter surveying a gravel quarry in Hartheim am Rhein, southwest Germany. The quarry is partially covered by artificial lakes. To determine the volumes of the above-water gravel dumping grounds and to map the bottoms of the lakes, high-precision data captured by a UAS was combined with multibeam echosounder data obtained by boat. Read the full article on this project on page 23.

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Ubiquitous UASs

The ubiquity of UASs is profoundly changing the surveying profession. The technology is already far enough advanced to make it possible to conduct surveys in previously inaccessible locations, the costs are relatively low, and the time savings are already significant and becoming greater year on year. We have talked about disruptive technologies before in *GIM International* and calling a new technique 'disruptive' is always risky. But the deployment of UASs in so many geospatial fields and subfields – such as cadastral surveying, cultural heritage and precision agriculture – demonstrates that UASs are everywhere and they are here to stay, and they are already influencing the way that surveyors and engineers are mapping and modelling the world. Various feature articles in this fourth edition of the *GIM International UAS Special* emphasise that change, such as the report by our contributing editor Frédérique Coumans who paints an optimistic picture of the positive impact monitoring and measuring from the air is having on agriculture (see page 20). The interview with Peter van Blyenburgh of UVS International, a non-profit organisation that represents over 2,800 stakeholders in 44 countries in the field of remotely piloted systems, sheds further light on developments. Van Blyenburgh still sees many regulatory obstacles, but states that Europe in particular is moving in the right direction to pave the way for more widespread UAS deployment and so too is the USA, although at a somewhat slower pace. Once the legislative situation is clear, UASs will be adopted so much faster that the way the average surveyor works will indeed change completely. This interview – see page 6 – makes a very interesting read in preparation for the future. Besides other articles and news from the world of unmanned aerial systems, we've also included an overview of UASs for mapping and modelling that are listed on Geo-matching.com, the product database affiliated with *GIM International*. I wholeheartedly encourage you to make use of this information source when researching, comparing or exploring the possibilities with UASs since the database contains all the technical specifications as well as brochures and videos relating to the manufacturers' products. In the meantime, in this fourth edition of the *GIM International UAS Special*, I hope you enjoy the high-quality, independent, in-depth background information on state-of-the-art developments in the UAS field. It sounds like a high-flying combination to me!


Photography: Arie Bruinsma

▲ *Durk Haarsma, publishing director*

GIM INTERVIEWS PETER VAN BLYENBURGH, PRESIDENT OF UVS INTERNATIONAL

Harmonising UAS **Regulations and Standards**

Many people dream of making a living out of remotely piloted aircraft systems (RPASs), but so far a lack of clear rules and regulations has stood in the way of that dream. However, there is a glimmer of hope on the horizon – especially in Europe – and best practices will spread across the world like an ink blot, according to Peter van Blyenburgh, president of UVS International. His independence from individual companies or governments makes him notoriously frank and he is an outspoken ambassador for the sector on all five continents.

Your main concern over the past decade has been the international co-creation of rules and regulations. Are you satisfied?

Never! But we are going in the right direction, especially in Europe. In December 2015, the European Commission submitted its 'Aviation Package' proposal to the European Parliament and the European Council for their approval. This covers, among other things, the integration of remotely piloted aircraft systems (RPASs) in the general European aircraft regulations and the modification of the basic regulation of the European Aviation Safety Agency (EASA). If the proposal is accepted, EASA will become responsible for the certification of all aircraft, including those weighing less than 150kg. That is the first step towards European harmonisation of the rules and regulations as well as the industrial standards pertaining to RPAS in the 28 EU member states, plus Switzerland and Norway. That's something they can still merely dream of on other continents. Governments and companies can only legally use drones if the local civil aviation authorities grant the required flight permits based on exceptions. The process in Europe will make it possible for the RPAS sector to look to the future with confidence leading to investment and hence growth. I believe that the effects of what is happening in Europe will be felt worldwide. Outside the European Union, individual regulatory authorities with limited resources will find it attractive to adopt these regulations because they represent a negotiated pact with broad acceptance. This would generally be more efficient and less costly than devising their own laws and training programmes.

But a European Regulation takes time; it's up to each member state to make its own laws on how to implement the Regulation and to decide what stance to take until it comes into force. It will take until late 2017 before proper, balanced business plans can be made. In the meantime, UVS International has started a multinational fast-track initiative to produce recommendations on safety rules for test & evaluation sites and also for public demonstrations and drone races. Neither of these topics are dealt with by EASA. The initial core team that will undertake this work consists of the RPAS communities in France, The Netherlands and Belgium, and they will shortly be joined by the communities from several other EU member states.

Which market size and growth figures are reliable?

There are no reliable figures so far; accurate statistics will not become available until the second half of this year. For now, there are only reports published by American companies which are aimed not at unreservedly presenting the facts but rather at dreaming up the largest possible market growth to motivate lobby groups, senators and the industry. The EU has recently commissioned the Boston Consulting Group to conduct a long-term market research study. The initial study should be completed by June 2016 to give a high-level projection of how the market and its segments look right now and how they will evolve over the next 25 years. The study concerns not only the commercial RPAS/drone market, but also public users such as the police, customs and suchlike and the recreational market, which will be the largest segment. Subsequent studies will refine that knowledge.

What is the current situation in the USA?

Things are starting to move in the USA, but slowly. As at February 2016, 3,459 exemptions had been granted by the Federal Aviation Administration (FAA) for limited commercial operations subsequent to petitions filed within the framework of FAA's Section 333 Exemption process. A new development that came into effect in December last year is that any US citizen aged over 13 (including hobbyists) who owns a small unmanned aircraft weighing between 0.55lbs and 55lbs must register it online with the FAA's Unmanned Aircraft System registry before they may fly it outdoors (at a cost of USD5). More than 330,000 owners have already registered, and any existing drone owners who have failed to do so could face civil and criminal penalties (see htt/www.faa.gov/uas/registration).

Further regulations are underway. If the FAA keeps its promise – which it has not always done in the past – subsequent to last year's Small UAS Notice of Proposed Rulemaking, it will publish its regulation for RPASs weighing under 55lbs this summer. This may even be published in time for the 2016 edition of the International Conference on Unmanned Aircraft Systems, which will take place in Washington from 7-10 June (www. uasconferences.com). During this conference, qualified military and civilian representatives will discuss the current state of UAS advances and the roadmaps to their full utilisation in civilian and public domains. Special emphasis will be given to current and future research opportunities and to 'what comes next' in terms of the essential technologies that need to be utilised to further advance UASs.

And in Asia?

Apart from in Japan, the scope of legal commercial RPAS operations in Asia is still rather limited. Several countries have basic regulations: China, Hong Kong, Japan, Nepal, the Philippines and South Korea. However, most of these countries are now in the process of updating them. Precision farming is offering interesting market possibilities, and Japan is a good example of this. Fifteen years ago, the agricultural aviation society, together with Yamaha, developed regulations and set up Yamaha flight academies – there are currently 27 of them – to train qualified pilots. Only operators who hold a qualification from those academies may lease Yamaha drone systems, which are used to spray insecticides and fertilisers, monitor crop growth, and so on. There are now approximately 2,500 drone operators active in the Japanese agricultural market and there have only been two accidents in the past 15 years. The Japanese market is broadening of course. The first commercial RPAS trade show in Japan took place in Chiba (www. japan-drone.com) from 24-26 March 2016. Promoted by the Japan UAS Industry Development Association, the event attracted more than 8,000 attendees.

Are things speeding up in China too?

Yes, they are. The first edition of the China Trade Fair on Unmanned Vehicle Systems was held in Shenzhen last year, organised by the Association for Unmanned Vehicle Systems of China. The Chinese are very keen to interact with the international RPAS community, as illustrated by the fact that I was asked to give no less than 15 interviews with the Chinese media at that time. The press representatives were interested in the importance of China participating in the international standards development efforts – specifically on product safety – and in the need for the Chinese private-sector RPAS community to start acting as a cohesive entity. A much larger event is scheduled for this September: the China International UAS Conference in Beijing (www.uaschina.net). This prestigious international conference, which focuses on safety, innovation, integration and R&D, is organised by the Chinese Society of Aeronautics & Astronautics and is co-hosted by the National Administration of Surveying, Mapping & Geoinformation, among others. The event is expected to attract 100,000 visitors!

▲ *Peter van Blyenburgh: "There are no reliable market figures so far."*

Can the professional market grow if the general public doesn't accept the large-scale use of drones?

No it can't. But privacy, to name the most important issue, is not a real problem in the professional market. The rules will be the same ▸

as for mobile mapping: people and number plates will be pixelated. National laws could make the rules even stricter. Drones can be equipped with electronic identity (registration) chips containing the drone's serial number and the owner's name. When a drone passes over you, you can use an app on your smartphone to view that information. This could make policing easier and facilitate filing a complaint. Our organisation is also contributing to the creation of a special website that will focus on awareness and understanding. Last October the European Commission awarded the 'Drone-Rules.EU Consortium' a contract to create the definitive European reference web portal. The initial edition of this website should be online by mid-2016 and the final version should become ready in the third quarter of 2017. It will increase awareness and facilitate understanding of the legal environment and constraints in relation to light RPAS operations (safety, privacy and data protection, insurance, etc.), with a focus on non-commercial operators. The portal will also facilitate access to the European market for commercial operators and showcase the opportunities for economic and job market growth. UVS International has already created www.rpas-regulations.com to make rules and regulations, as well as related reference documents, available to the international RPAS community. This website monitors 267 countries and overseas territories and includes a section with information about Europe. The RPAS 2016 conference (www.rpas-conference.com), which is taking place in Brussels, Belgium, on 22 and 23 June 2016, will also provide a good view of what is happening in Europe. For the past 18 years, this has been Europe's principal event on RPAS-related regulatory matters, pilot training, operator and pilot responsibility and liability, insurance, data protection and privacy, and suchlike.

Many people in the geomatics branch feel drawn to UASs. Are they better informed?

No, apart from a handful of them. I have spoken with many geomatics professionals all over the world; they see dollar signs in front of their eyes and dream of building sexy aircraft or opening up a geo-drone shop. But when I tell them about the liabilities, they look at me as if I want to rain on their parade. Your company will be torn apart if there's an accident with a drone! They don't realise that the aviation world is a totally different ball game than ground-based surveying and geomatics. They think drones are toys because the devices are easy to use, but you have to be very well insured and the insurance companies' certification demands increase in relation to the complexity of the flight mission. For small and medium-sized enterprises, the real profit lies not in the application of the aircraft but rather in the data collection, processing and analysis.

What will UASs still not be able to do by the end of 2017?

Let me rephrase the question, because in two years' time the professional systems will certainly be technically capable of doing almost anything that is currently done by a surveyor, aerial photogrammetry, Lidar or a very-high-resolution satellite – and with the same or higher precision, faster and at a fraction of the total cost. But what will a UAS still not be able do *legally* in two years' time? It's all about insurance. If you're not insured, you are acting illegally and you will not be able to present a good enough business case. Looking to Europe, within approximately two years from now there will be one set of European rules which an insurance company will force you to comply with. The rules may be different in the rest of the world, but I think the European rules will spread like an ink blot. In any case, the possibilities will be limited to flights under 500 feet (150 metres) since above that height there is too great a risk of possible collision with other aircraft. For a while, the second limit will be – as a rule – that the drone has to be in sight of the remote pilot at all times. But the nice thing about the existence of a formal legal framework is that you can arrange exceptions for specific projects. For instance, when a project concerns trajectory observations – roads, railways, dikes, dams – or mapping or surveillance applications over large non-urban areas, insurance companies will be more willing to make an exception to the line-of-site rule in proportion with the lower risks.

Will the surveyor become obsolete?

I believe that aerial photogrammetry as we know it today for mapping purposes will become obsolete, but the surveyor will not. Surveyors will still be needed in dense urban areas. Flying in urban canyons is complicated and new technologies must be developed for situations in which buildings are close together or there are different building lines. In the meantime, surveyors will have to help determine the air corridors for the flight plan, and they can of course operate the drones.

What is the current focus of the largest, non-military R&D investments?

The biggest investment is being made in air-traffic management: manned and unmanned aircraft in the same airspace and at airports. In the EU's Single European Sky ATM Research (SESAR) programme alone there are 19 projects working on developing innovative technological and operational solutions. The funding amounts to EUR500,000 per project, which is actually a rather low budget. The total sum is enormous when all national and European investments are added together but there is a large degree of overlapping, duplication and re-inventing the wheel. What would save a huge amount of money is a register, because nobody knows what is being done worldwide. All those researchers and engineers travel around the world from one conference to the next, but they focus on minor differences between their research plans to defend their spending.

There should be a worldwide database – or just a European one for starters – containing all research projects that are even remotely related to UAS technologies. Who is involved, what are the goals, the programme, the budget, evaluations, contact data and so on?

Then everybody can verify whether what they want to do is really new, and the large companies can use it to see what interesting research is already being done and, of course, who the promising students are. Such a register would cost only a few million to build and maintain, but the added value would be enormous. Most universities say they would like to participate, but when it comes to building the system they don't have the time. Perhaps it's not in their interest to have such openness?

Which development will shift everything up a gear?

We're now aiming at pushing product safety. UVS International has initiated the RPAS Autopilot Validation Tool Group, which has developed an inspection algorithm for autopilots – one of the most crucial parts of a remotely piloted aircraft. The study group brings together important industry players from Europe as well as Canada, China and the USA. They have determined the required functional capabilities which the algorithm has to fulfil. This model will be integrated in a laptop which will be hooked up to the autopilot of the aircraft that has to be inspected. The laptop will be used to program the various flight missions that the autopilot has to perform. Those missions will be flown virtually and during the flights the autopilot will be presented with internal and external problematic events. How does the autopilot react? How precisely is the flight plan executed? The algorithm will measure the results. Depending on the grading, the system would then receive the European CE quality mark of product safety – or not, as the case may be. This would set a very useful industrial standard. If the autopilot does not obtain the predetermined grade, it will be difficult to obtain insurance for the related drone system. The next step now is to supply the study results to the European authorities so they can use them as the basis for a public tender to produce the required algorithm. ◂

Photos: Jeroen van Berkel.

Peter van Blyenburgh

Peter van Blyenburgh has been involved with unmanned aerial systems since 1987 and supplies advisory services in this field to corporate and governmental entities in Europe, the Middle & Far East and North America. He is president of UVS International (www.uvs-international.org) which he founded in 1997. Van Blyenburgh is an active participant in many RPAS-related international working groups and advisor to EUROCARE WG73, honorary member of the European Group of Institutes of Navigation, The European Institute (in the USA), UVS France and a member of the Air Traffic Control Association.

Operating out of Paris, France, UVS International is a non-profit organisation that represents over 2,800 stakeholders in 44 countries in the field of remotely piloted systems. Manufacturers, operators, service suppliers, research organisations and academic institutions are represented on a worldwide basis in all the competence areas that matter. The annual publication RPAS: The Global Perspective is regarded as the world's leading reference work on RPAS (1st edition in 2003). See www.uvsinfo.com.

THE CURRENT STATE OF THE ART IN UAS-BASED LASER SCANNING

Airborne Laser Scanning Using UASs

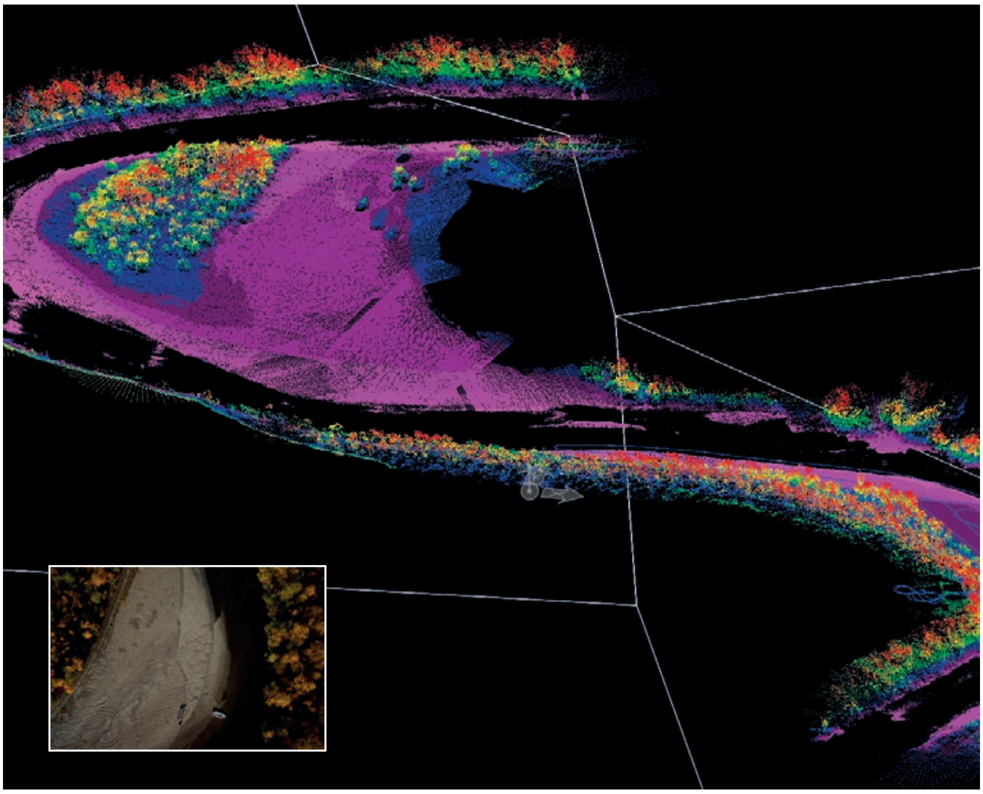
Airborne laser scanning (ALS) offers a range of opportunities for mapping and change detection. However, due to the large costs typically associated with traditional ALS, multi-temporal laser surveys are still rarely studied and applied. Unmanned aerial systems (UASs) offer new ways to perform laser scanning surveys in a more cost-effective way, which opens doors to many new change-detection applications. This article discusses the suitability of the two main types of UAS platforms – fixed-wing systems and rotorcraft – and the current state of the art in UAS-compatible laser scanning systems

▲ *Figure 1, Launching a small UAS for a topographic laser scanning mission in the Finnish Arctic. Multi-temporal laser scanning data is collected to monitor Arctic river bed morphology.*

The use of UASs for laser scanning is a relatively new area of research and applications. One of the starting points in 2006 was a remotely controlled helicopter supplied with navigation sensors and a laser range finder (altimeter) suitable for topographic surveys. The use of larger UASs with laser scanners has been studied for almost a decade now and is fuelling plenty of discussion about the possibilities of UAS-based laser scanning in the industry.

UAS PLATFORM COMPARISON

UASs can generally be categorised into two types: fixed-wing aircraft and rotorcraft. Each type is suitable for specific applications and tasks. Fixed-wing systems typically provide users with a longer operation time and support larger payloads due to better fuel economy. Fixed-wing systems also allow for more speed, which makes this type of UAS more suitable for large areas or long-distance missions. The fixed-wing platform is more stable in flight than a rotary-wing platform, the latter struggling with inertia in a more complex way. On the other hand, fixed-wing systems need more space at turns, thereby increasing the path length and decreasing efficiency. In addition, fixed-wing UASs need more space for take-off and landing, which makes them less suitable for remote areas where little or no infrastructure is present. From a data acquisition perspective, the higher speed of fixed-wing platforms reduces data density or requires more-expensive high-performance sensors to reach a certain point density. In summary, these restrictions make a fixed-wing platform less favourable for small-area surveys with complex terrain or objects rich in features that need to be captured. In contrast, rotorcraft allow for slow or even stationary flight speeds. They offer excellent manoeuvrability and do not require an airstrip for take-off and landing. This enables the use of relatively low-cost sensors, which makes UAS-based laser scanning accessible to a wider user community.



▲ *Figure 2, Point cloud data collected with a small UAS for mapping ground topography and vegetation in great detail.*

INDUSTRIAL SYSTEMS

There are several industrial scanners that are equipped with affordable sensors suitable for UAS laser scanning. Most of these sensors are designed for industrial applications and robotics (manufactured by, for example, SICK, Ibeo and Hokuyo). The main advantages of these sensors are their low price, small size and durability, all of which are advantages for UAS-based laser scanning. However, the performance of these types of sensors is limited. The speed of data collection, ranging accuracy, limited maximum range and often lack of implemented or available signal processing techniques means that they are not always suitable for commercial heavy-user operations, but they suffice for many other (research) applications. Other UAS-compatible systems that have recently emerged are multi-layer laser sensors originating from the automotive industry, such as Velodyne LiDAR Puck LITE and Quanergy M8-1 LiDAR. These systems offer high data rates and some of the other desirable features at a reasonable price. Multi-layer data capture improves the along-track sampling while the 360-degree field of view enables more comprehensive data collection of complex scenes such as the urban environment.

PROFESSIONAL SENSORS

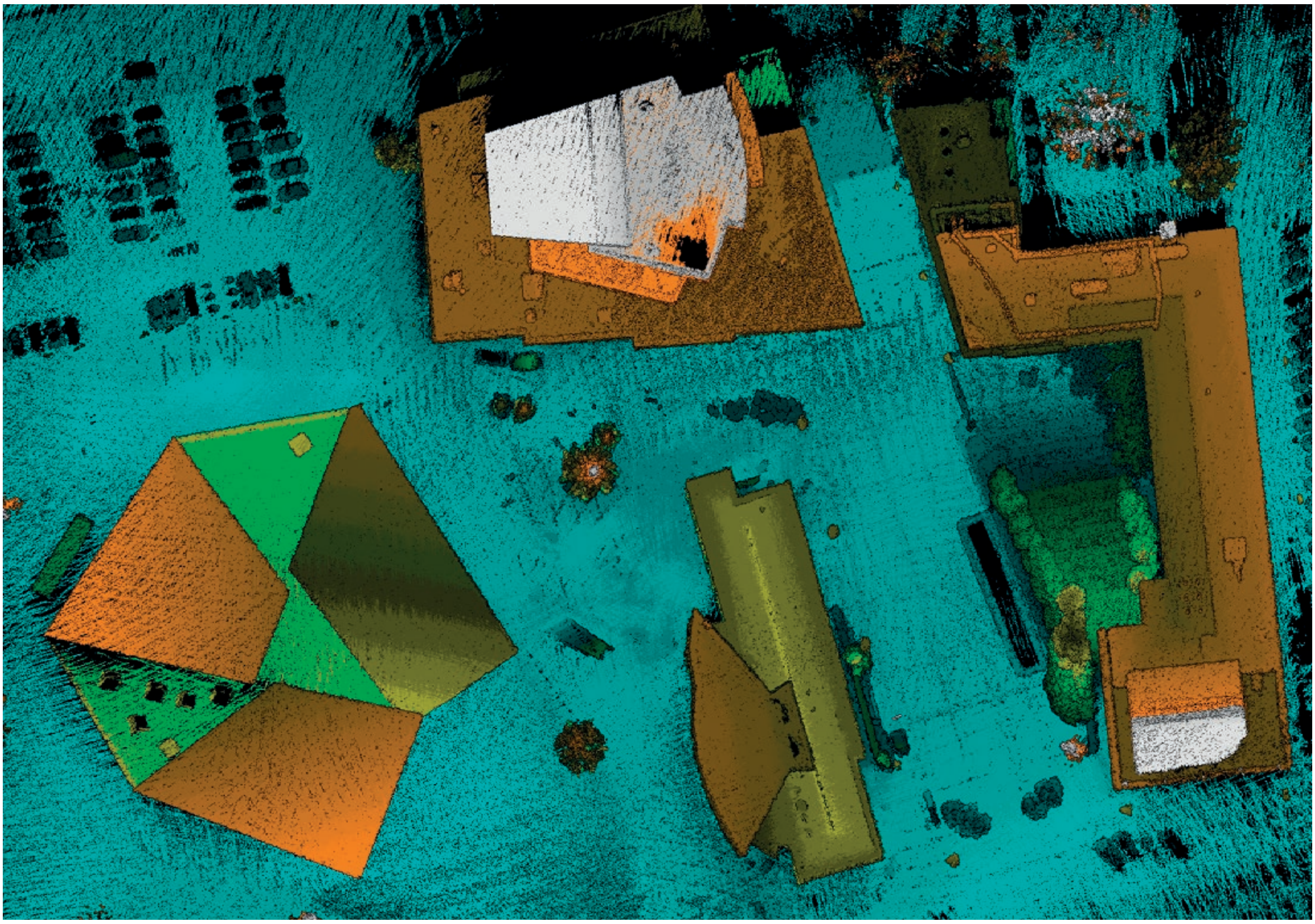
UAS-specific sensors are designed for airborne operations and their specifications make them more suitable for professional use. Their design effort, however, has a clear effect on pricing and the systems from this product class have price tags starting at tens of thousands of euros. Placing such a sensor on a UAS significantly increases the overall system costs. This has a negative impact on exploiting their capabilities for the mapping industry. Examples of professional sensors are Riegl VQ-480-U or VUX-1 variants, which are full-performance sensors. They allow for operations at high altitude (500¬-1,500 metres). At these altitudes, however, a manned aircraft is often a more convenient approach, also because of the strict regulations for UASs.

EXAMPLE OF A LOW-ALTITUDE UAS

The previously mentioned Hokuyo and Velodyne LiDAR Puck LITE are examples of sensors that are suitable for low-altitude missions, which is the typical prerequisite for UAS operations due to safety regulations. These sensors can operate at flight altitudes of up to 100 metres, but in practice typical operation altitudes are 40-70 metres. The flight capability of the small UAS shown in Figure 1 is about 20 minutes including a safety margin, but the flight time also depends on the wind conditions. This results in a flight path length of between 1.5 and 2 kilometres. With a field of view of 60 degrees and a flight altitude of 70 metres this makes it possible to capture a strip of 80 metres wide. Figure 2 shows an example of point cloud data collected with the Hokuyo UXM-30LXH-EWA for mapping river bed topography. The inset shows an aerial image of the smaller point bar (which was also acquired with a UAS).

UAS FOR URBAN REMOTE SENSING

Applications in the urban environment are diverse and may vary from general area mapping for building planning purposes to fine-scale detection of power line components for maintenance purposes. The urban space is often busy. There is little margin for error correction and malfunctions pose a high risk of damage to people and property, meaning that it can be challenging to apply UASs in the urban environment. Nevertheless, it is regarded as an interesting new technology offering a range of new mapping and change-detection applications. The data in Figure 3 was collected using a rotary-wing UAS equipped with a Velodyne LiDAR Puck. The sensor package used here also included a NovAtel IGM-S1 GNSS-IMU device for observing and recording the sensor flight path and orientation. The platform executes the flight plan autonomously while the progress of operation is viewed on a display connected to the system via WLAN. The accurate (corrected) flight path is computed during post-processing using GNSS base station data or data from a virtual network, after which the point cloud data is computed. Point cloud accuracy directly depends on the flight-path solution accuracy but also on the relevant sensor performance. At best, one can expect to obtain a point cloud accuracy of 5 to 10cm. The point densities in the data can be between dozens and ▶



▲ *Figure 3, Architectonic urban scene mapped with a Velodyne LiDAR Puck laser scanner mounted on a small rotorcraft. The 360-degree field of view allows for simultaneous capturing of roofs and walls.*

thousands of points per square metre, which is a much larger number compared to that of a traditional ALS dataset (1-20 points per square metre). The wide field of view of the sensor allows for simultaneous capturing of the terrain, street infrastructure, building walls and roof structures.

EMERGING TECHNOLOGIES

Looking to the future, flash Lidar technology(e.g. ASC TigerCub) is a promising development for UAS laser scanning. Flash Lidar allows for fast data acquisition rates with simultaneous areal coverage and overlap due to framed sensing. This enables the multi-look principle for data acquisition, which improves object detection and recognition. However, flash Lidar sensors are very expensive at the moment and, due to their military origin, only limited knowledge is available in the civil domain. Another interesting trend is the development of solid state photon counting sensors in various sizes: larger sensors suitable for use with manned aircraft or large UASs, or extremely small and lightweight sensors based on single photon avalanche diodes (SPAD). In research laboratories, SPAD sensors can reportedly already achieve the same ranging performance as the current low-cost industrial laser scanners. When fully developed and operational, these sensors will definitely change the UAS-based laser scanning field in the years to come.

LOOKING TO THE FUTURE, FLASH LIDAR TECHNOLOGY IS A PROMISING DEVELOPMENT FOR UAS LASER SCANNING

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CAPABILITIES FOR PRECISION FARMING AND HEAT MAPPING

Multispectral and Thermal Sensors on UAVs

Mini and micro unmanned aerial vehicles (UAVs) in combination with cost-efficient and lightweight RGB cameras have become a standard tool for photogrammetric tasks. In contrast, multispectral and thermal sensors were until recently too heavy and bulky for small UAV platforms, even though their potential was demonstrated almost a decade ago. Nowadays, however, lightweight multispectral and thermal sensors on small UAVs are commercially available. The authors investigate their capabilities for use in precision farming and heat mapping.

The multispectral cameras and thermal infrared (TIR) sensor in the authors' performance tests were mounted on an eBee from senseFly. Based in Cheseaux-Lausanne, Switzerland, and founded in 2009, senseFly manufactures fixed-wing UAVs and equips them with customised lightweight cameras developed by Airinov, which is based in Paris, France. Focusing on precision farming, Airinov modifies Canon cameras into multispectral sensors and manufactures the multiSPEC 4C multispectral camera and the thermoMAP thermal infrared sensor. This study tested the Canon S110 NIR and a prototype version of the multiSPEC 4C, both of which are multispectral cameras, as well as the thermoMAP, a TIR sensor.

UAVS AND SENSORS

The lightweight fixed-wing eBee can be operated fully autonomously, requires hardly any piloting skills and is ideal for covering larger areas. The eBee family is marketed in conjunction with customised sensors which can be controlled by the autopilot of the fixed-wing UAV. The Canon S110 RGB is a low-cost colour camera, the Canon S110 NIR and S110 RE are low-cost multispectral cameras while the multiSPEC 4C is a high-end system. The Canon multispectral cameras are equipped with modified Bayer colour filters – instead of recording blue, green and red, the green (G), red (R) and near infrared (NIR) bands are captured. Just one lens is needed resulting in precisely co-registered spectral channels with overlapping spectral sensitivities (Figure 1). In contrast, the multiSPEC 4C has four lenses and four monochromatic CCD sensors; the colour separation takes place at the optical units via band-pass interference filters with well-defined central frequencies and bandwidths (Figure 2). A zenith-looking panchromatic sensor enables the images to be normalised. Table 1 provides details of the above-mentioned sensors.

A RAPE FIELD WAS FLOWN AIMED AT DETERMINING OPTIMAL HARVESTING TIME AND CROP YIELD ESTIMATES RELATED TO SPECIES AND TREATMENT

Sensor property	Canon S110 NIR	multiSPEC 4C Prototype	multiSPEC 4C Commercial	ThermoMAP
Pixels per sensor	12MP (Bayer pattern)	4 sensors, 0.4MP each	4 sensors, 1.2MP each	0.3MP (640 x 512)
Sensor size [mm]	7.44 x 5.58	4.51 x 2.88 (per sensor)	4.8 x 3.6 (per sensor)	10.88 x 8.70
Pixel size [μm]	1.33	3.75		17.0
GSD at 100m AGL	3.5cm	20cm	10cm	18.5cm
Spectral channels (central frequency/ opt. band width) [nm]	G (550) R (625) NIR (850)	G (550 ± 20) R (660 ± 20) RE (735 ± 5) NIR (790 ± 20)		7,000-16,000
Approx. price [EUR]	900	Prototype	8,000	10,000

▲ *Table 1, Main features of the sensors in the tests.*

TEST FIELDS

Test fields of the Agricultural Centre Liebegg (AG, Switzerland) with different crops were captured by the Canon S110 NIR and multiSPEC 4C. A rape field was flown aimed at determining optimal harvesting time and crop yield estimates related to species and

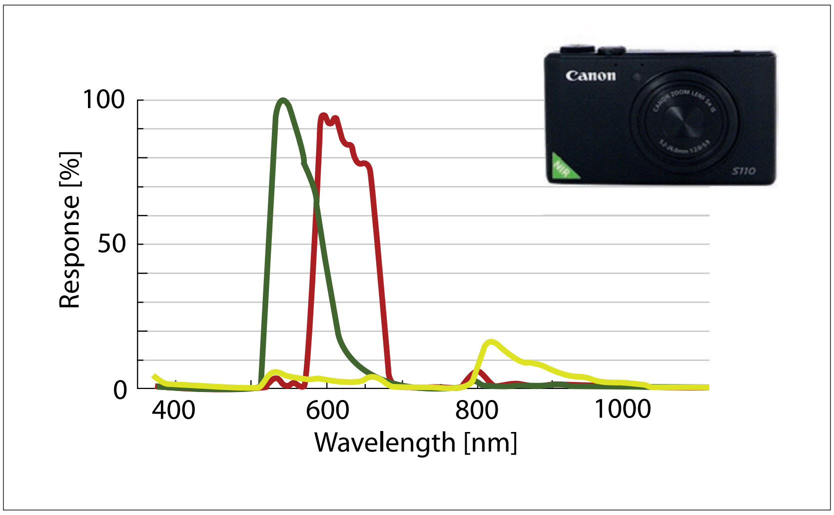

Figure 1, Spectral sensitivities of the Canon S110 NIR normalised with respect to the green band (100%).

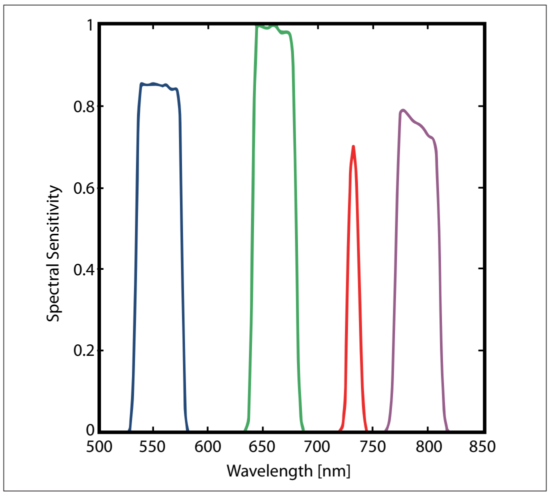

Figure 2, Spectral sensitivities of the MultiSPEC 4C normalised with respect to the green band (100%).

treatment. A second study captured several fields, including:

- a wheat field with different fertilising strategies
- a beetroot field with potential fungal infestation
- a potato field aimed at determining the optimal time for crop desiccation and monitoring of potato blight, a devastating disease which caused the Irish potato famine of the mid-19th century

In each field, three to seven ground control points (GCPs) were established with a horizontal and vertical point accuracy of 2cm.

DATA

A total of 24 flights were carried out, each lasting 20-40 minutes and capturing 40 to 900 images, each with a ground sampling distance (GSD) of between 2.5cm and 10cm. The multiSPEC 4C prototype showed some limitations due to its reduced sensor dimensions and resolution and high power consumption. The processing of the imagery was done with the standard software Postflight Terra 3D and included:

- image orientation/bundle block adjustment
- generation of a digital surface model (DSM) by means of dense image matching
- orthoimage generation and mosaicking
- calculation of reflectance maps and vegetation indices

The processing of MultiSPEC data was preceded by a radiometric calibration of the individual channels, carried out using images of a calibration table. The accuracy (1 sigma) of the image orientation was 0.2-0.3 pixels, equivalent to 1.5-4cm in object space.

RESULTS

The multiSPEC and Canon S110 NIR images were compared with data captured by a calibrated portable field spectrometer, which records the range of 360-1000nm with a spectral resolution of 3.3nm and features a zenith-directed reference channel. As the normalised difference vegetation index (NDVI) is based on reflectance ratios [NDVI = (NIR – R) / (NIR + R)] no calibrated or normalised reflection values are needed. The NDVI ranges from -1 to +1. On average the NDVI values of the multiSPEC 4C deviate by -0.04 from the reference values. For the S110 NIR sensor the average difference is -0.260. This large value is caused by the overlap in the spectral channels.

The vitality of the plants and the potential for crop yield estimation were assessed based on the NDVI values of the rape test field. Although the flight campaign had been delayed due to bad weather in summer 2014 and could only be conducted a few days before harvest, distinct vitality

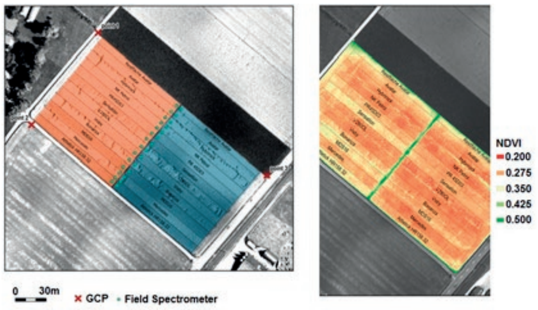

Figure 3, Rape test field (left) with fungicide treatment (orange) and without treatment (blue) and the NDVI map derived from MultiSPEC 4C data, GSD 10cm.

differences could be detected between individual species and between areas with fungicide treatment and untreated areas (Figure 3). Treatment with fungicides leads to a prolonged plant activity up to harvest time. The normalised correlation coefficient between crop yield and NDVI values for treated fields was calculated as 0.78. For untreated fields the coefficient was calculated as 0.35.

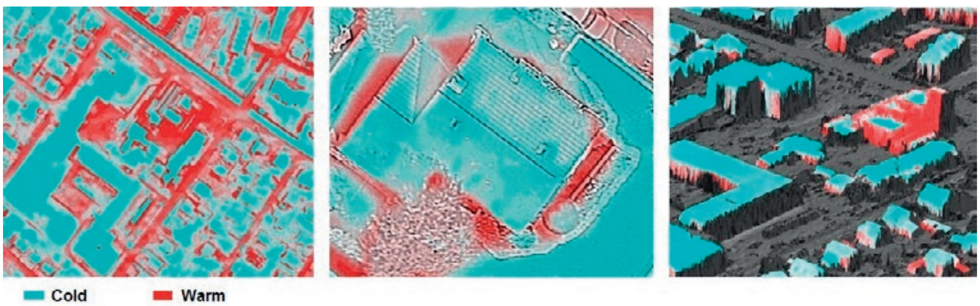

Figure 4, TIR orthoimage with a GSD of 15cm (left), pan-sharpened TIR orthoimage with a GSD of 5cm (middle) and 3D roofscape.

TIR SENSOR

To determine the capabilities of the thermoMAP sensor, two campaigns were carried out on 13 March 2015 immediately before and after sunrise. The images were captured with a GSD of 15cm and 30cm. In order to create a DSM of the area using dense image matching, overlapping RGB images were taken with a Canon S110 RGB during the daytime, capturing images with a GSD of 5cm. The data was processed to obtain TIR orthoimages with a GSD of 15cm, a pan-sharpened TIR orthoimage using the RGB imagery for sharpening resulting in a GSD of 5cm, and a DSM overlaid with the TIR orthomosaic resulting in a 3D roofscape (Figure 4). During these first experiments, the thermoMAP showed firmware problems which prevented the conversion of the measured values into surface temperatures. Nevertheless, the data provides valuable information for building-energy experts.

CONCLUDING REMARKS

The high-quality measurements, irrespective of lighting, by high-end multispectral sensors, make them suitable for monitoring vegetation over time without a need for laboriously acquiring spectrometer reference data in the field. Low-cost multispectral sensors combined with a high GSD up to the centimetre level are well suited for monitoring in-field variability and for detecting plant diseases in, for example, very expensive specialty crops.

FURTHER READING

- Nebiker, S., Annen, A., Scherrer, M., Oesch, D. (2008) A Light-weight Multispectral Sensor for Micro UAV – Opportunities for Very High Resolution Airborne Remote Sensing. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Beijing, China: ISPRS, pp. 1193–1200.
- Nebiker, S., Lack, N., Abächerli, M., Läderach, S. (2016) Multispectral and Multitemporal Imagery from UAV for Predicting Grain Yield and Detecting Plant Diseases. To appear in: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. XIII ISPRS Congress, Prague, Czech Republic.

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CAPTURING A HIGHLY SECURED SITE FROM THE AIR

Modelling Prague Castle with a UAS

To obtain detailed and accurate orthoimages and 3D models to support technical staff in maintaining Prague Castle, the site was captured by UAS photogrammetry. Videos and georeferenced panoramic images were also taken as a service to documentalists and to provide the basis for virtual tours for tourists. Prague Castle and its surroundings are heavily secured sites and special permission was required to conduct the air survey.

▲ *Figure 1, Manual take-off.*

From the 9th century onwards Prague Castle, located on the banks of the River Vltava in the centre of Prague, Czech Republic, was the residence of the country's royal family and since 1918 it has been the residence of the president. At 570m long and 128m wide it is one of the world's largest castles, plus it is the largest ancient castle on the planet. It is a symbol of both the city and the Czech Republic as a whole. Various Czech kings have been crowned and entombed in St. Vitus Cathedral, located within the castle complex.

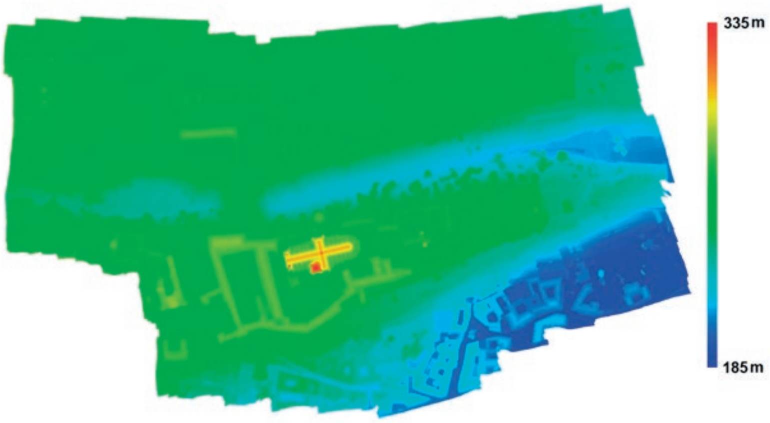
UAS EQUIPMENT

The Prague Castle zone is heavily guarded. Conducting UAS flights over the one-square-kilometre site is strictly forbidden and the fine for doing so can amount to EUR200,000. As the first and largest Czech UAS company registered at the Czech Civil Aviation Authority (CCAA), Upvision obtained permission to fly over the secured area in 2015. The UAS used was the Mikrokopter, a hexacopter built by the company itself and licensed by CCAA for conducting mapping and other commercial aerial missions. The Mikrokopter was equipped with a calibrated Canon EOS 700D camera with a 28mm lens fitted on a servo gimbal. Spherical panoramic photos were taken using a Canon EOS 700D camera equipped with a fisheye lens, also mounted on a gimbal. Video was captured with a Panasonic GH4 affixed to a brushless gimbal for absorbing vibrations. The positions obtained by the on-board GNSS receiver, which acquired both GPS and GLONASS signals, and the measurements from the inertial measurement unit (IMU) were tagged to the images directly during exposure.

THE AMOUNT OF GEODATA COLLECTED APPROACHED NEARLY 100 GIGABYTES

SURVEY

Five flights were carried out in the early morning of a working day when the president was away and the castle was not yet open to tourists. There was little wind and the sky was clear. Each flight lasted around 13 minutes and the entire survey could be finalised within little more than one hour. As the highest tower of St. Vitus Cathedral is taller than 100m, a flight altitude of 150 metres was adopted resulting in a ground sampling distance (GSD) of 2.4cm. High image overlaps – 80% along track and 60% across track – were chosen because of the many tall buildings. The take-off location differed per flight and was selected such that it was in the middle of the area to be covered to ensure that the pilot could maintain sight of the UAS during the entire flight, from take-off to landing. After manual take-off (Figure 1), the UAS was flown in automatic mode.



▲ *Figure 2, DSM, cross shape: St. Vitus Cathedral.*

Landing was then performed manually. The flights took place in the presence of soldiers of the Castle Guard. As it would have been inappropriate to paint ground control points (GCPs) on such a historic site, a total of six natural GCPs were used. For checking purposes five control points, likewise natural objects, were identified. The control points were measured by the real-time kinetic (RTK) technique using TopCon Hiper GGD and processed with TopSurv software.

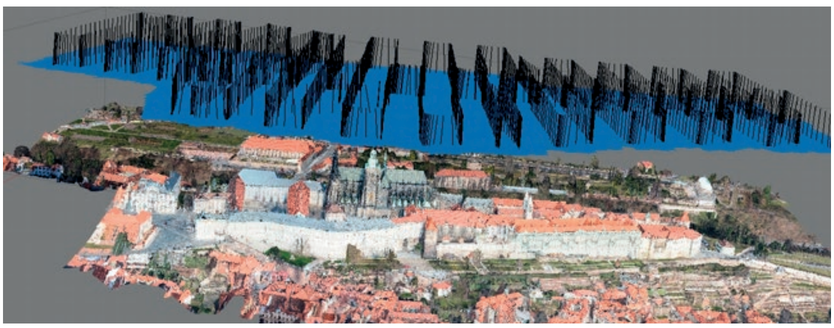
PROCESSING AND OUTPUT

The area of nearly one square kilometre was captured by 1,595 images. The amount of geodata collected approached nearly 100 gigabytes. The images, external orientation parameters and flight logs were uploaded and processed with Agisoft Photoscan Pro. During block adjustment, over four million tie points were created. The coordinates of the GCPs were determined with a root mean square error (RMSE) of 5cm. The processing resulted in a georeferenced (Czech coordinate system) digital surface model (DSM) consisting of nearly 400 million points (Figure 2), a mesh model and an orthomosaic with a GSD of 2.4cm (Figure 3). The processing took two days on advanced hardware.

▲ *Figure 5, Spherical image in little planet projection.*

The orthomosaic, in addition to complementing the existing maps and technical drawings of the castle, was draped over the DSM to create a 3D model of the area (Figure 4). The 3D model will not only be used for visualisation purposes but will also serve as a detailed information source in helping technical staff to maintain the historic buildings as well as providing documentation for other projects. The above-mentioned outputs will be integrated in the GIS of the Prague Castle Administration. In addition, the panoramic images were processed to generate interactive spherical views used for the creation of a virtual tour (Figure 5). The video and the virtual tour will be accessible through the Prague Castle website (www.hrad.cz). ◀

▲ *Figure 3, Part of the orthomosaic and detail (left).*



▲ *Figure 4, 3D model showing a preview of aerial images.*

JAKUB KARAS

Jakub Karas is co-owner of Upvision, manager and consultant. He has been specialised in photogrammetry and GIS for over 14 years. He also chairs the Czech UAS Association.

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GREATEST POTENTIAL ON SMALL FARMS

UAS-supported Agriculture: Still for Innovators

While unmanned aerial systems offer huge possibilities in modern farming, most of them lie in the future. These airborne vehicles currently mainly deliver images that are subsequently combined with other input in the farm-specific management system. In the future they will be able to contribute to land management and individual crop-product delivery based on real-time analysis. Another very promising segment for UAS-supported precision agriculture is water management.

Precision agriculture is a relatively young concept, dating from around the turn of this century. The first products were focused on add-on guiding systems for tractors. These give a good return on investment, generating savings in fuel and time by avoiding overlaps and gaps when farming a field. Although the financial benefits of these and subsequent products are very convincing, precision agriculture is still the domain of the large, high-yield farmers in 2016. However, the definition of 'large' differs around the world: from 500 hectares in France, to 5,000 in the USA and 50,000 in Ukraine. To put this into perspective, according to the Food and Agriculture Organisation of the United Nations (FAO) in 2014, there are 570 million farms worldwide and only 1% of them are larger than 50 hectares. The value of the crop is also a factor. For example, tulips in The Netherlands, rice paddy fields in South Asia or vineyards in California are more likely to justify the farmer's investment – in terms of both money and the need too acquire a lot of new knowledge.

▲ *Jim Watt: "The technology is there, but perhaps we'll have to turn around a part of the concept to fit in with the health and safety regulations." (Photo: Jeroen van Berkel)*

Whereas 'ground-bound' precision farming is in the early adoption phase globally (although that is a phase of strong sales growth), only the most innovative farmers are enjoying the benefits of unmanned aerial systems (UASs). "It is still early days for UASs in precision farming," confirms Jim Watt, regional director of Trimble's Agricultural Division in Munich, Germany, who has provided advice on business development for precision agriculture almost everywhere in the world. "The people in this business are still working out what the value chain exactly is." The return does not come cheap. All over the world, pilots have to be fully licensed and insured, and some countries make extra demands (for instance, the UK also stipulates a second observer).

Ultimately, the UAS produces an image. "The image itself has little value, but after software treatment it's all about the total system – that can tell you differences in crop vigour, the location of pests or weeds or even errors in planting or application caused by malfunctioning equipment. Invariably, you have to involve a data specialist to help convert the image into information and a commercial agronomist who delivers specific services, from image interpretation to agronomic recommendation," continues Watt.

MAIN SELLING POINT

What attracts the innovators to UASs? After all, they could also use a satellite or an aircraft to obtain the images. Watt states: "One main selling point is availability." Service providers can often conduct flights on the same day. And the other benefit is resolution: "The cameras are very sophisticated and near to the ground so you are down to centimetre resolution. You can drill down to very high accuracy to see if, and exactly where, there is variation in the crop." The resolution is so

▲ *"A global regulation dictates that a UAS must always be in the line of sight but fields on some larger farms may be a kilometre long. A scheduled flight path could provide the solution." (Photo: Trimble)*

good that farmers and their agronomists are able to detect the level of plant emergence in their fields, which can be an early indicator of upcoming crop yields.

Farmers and agronomic service providers in the USA were the first to adopt this technology, followed by Australia. The business model of the farms there is less subsidy-driven than in Europe and farmers strive for ultimate efficiency. But over the last few years subsidy requirements have been a very strong driving force for UASs in Europe and that continent now has the largest user community. The need to be accountable to the EU and national governments, in exchange for agricultural or environmental subsidies, is driving European farmers to make intensive use of IT. Another major issue is food traceability, and a third reason is the loss of knowledge that was traditionally passed down through families. Farmers' sons used to know which areas of their fields would produce a lower yield because their fathers told them so while looking over the fence.

YOU CAN DRILL DOWN TO VERY HIGH ACCURACY TO SEE IF, AND EXACTLY WHERE, THERE IS VARIATION IN THE CROP

But now, due to the consolidation in the sector in Europe, farmers or contractors need agronomic and productivity data because they are strangers on their own land.

Pests, herbs, weeds, irrigation patterns: it is possible to build up a picture of what is happening in the soil by combining map layers and that is where a UAS comes in. Watt: "But all the data has to go into the farm's management information system. Only then can you know what to do, i.e.. that specific area in that field needs that specific cultivation practice. With UASs you get better images and in a much shorter time frame." Trimble uses the Connected Farm data management system as the all-encompassing instrument to manage information from whatever source. Although Trimble has its own UAS, called the UX5 Aerial Imaging Solution, it welcomes UAS input from other systems as well as data from, for instance, water management systems or soil profiles. For Trimble, the technological R&D synergy between precision agriculture in general and the UAS segment lies mainly in the data management aspect plus to some extent the use of software for image refinement.

WATER MANAGEMENT

In agronomy, developers are also concentrating on how UASs can be used for water management. Agriculture accounts for 70% of the world's total fresh water consumption, but water is a very expensive resource and it is becoming increasingly scarce. Even in the UK, which has suffered serious flooding and long periods of rainfall, there are some parts of the country where no rain has fallen in four months. As a Brit by birth, Jim Watt monitors the situation. "The rain doesn't fall in the period that it is needed, so nothing will grow there. Worldwide, the problem of aridity is huge. Irrigation management – to have the right amount of water available at the right time, in the right places – is very important in many countries, not only in Sub-Saharan Africa. UAS-supported water management is one of the priorities. UASs are used for taking images and doing very high resolution topographical surveys. You can follow up the plant stress and use the images for drainage planning, to plan irrigation control systems or detect water leaks." A UAS allows the farmer or contractor to be able to acquire images of their fields just moments after heavy rainfall. Only such timely images can show weaknesses in the farm's topographic state, and satellite or aircraft-derived images may not be able to be acquired and delivered to the farmer soon enough.

BETTER FOR SMALLER FARMS

While those kinds of specific applications are attractive, regulations, payload restrictions and inefficient data handling are currently placing serious limitations on UAS use for large plots. Whereas a global regulation dictates that a UAS must always be in the line of sight, to fly the length of a whole field on some larger farms may entail a distance of a kilometre or more, and then back again. "If you could do that on a regular basis, on a scheduled flight path that is planned and programmed, then you would be talking about greater utilisation and ability," says Watt.

In terms of farming regulations, Japan has been a pioneer and therefore the country's agricultural UAS market is mature, with UASs already being used for crop treatments. Watt continues: "The modern UAS is efficient for the Asian type of farming with rice paddy fields of half a hectare or less, but the systems simply don't have the range for treating an average maize farm in the US or wheat farm in Ukraine. And if you want to use the UAS for carrying a payload of liquids – pesticides, fertilisers, etc. – there are severe limitations. The battery lasts for about 60 minutes and you can load it with a kilo of chemicals…but what can you do with a kilo? Flying with chemicals in the air is also a problem." From a marketing perspective, however, it is not necessarily a problem if UASs are limited to smaller farms since 74% of all farms worldwide are two hectares or less. Watt agrees: "We're a long way from having a total solution for larger farms because of the payload and regulatory limitations, so today there is more potential on small farms. But if you could fly to a specific plant and treat it with a chemical, that would be a game changer for farms of all sizes. In order to be able to do that, the inability to transfer huge amounts of data during the flight from the UAS to the ground also has to be tackled."

WE'RE A LONG WAY FROM HAVING A TOTAL SOLUTION FOR LARGER FARMS BECAUSE OF THE PAYLOAD AND REGULATORY LIMITATIONS

PRECISION TREATMENT

It would be a real bonus if the UAS could deliver something – a pesticide, a laser beam, etc. To facilitate spot-specific spraying, the UAS has to identify the problem with the plant, interpret that image in real time and distribute that information to the agronomist at the farm. "At the moment you need a number of market players in the value chain to get to a solution like that, and you have to transmit a tremendous amount of data from a vehicle in the sky. But the technology is there. The battery has to last longer, perhaps with solar power. In the military they can carry huge payloads of weaponry and fuel to fly enormous distances. The regulations dictate how big a distance we can fly and the weight of the vehicle currently determines the limitation band. If there were no limitations, we could make much larger UASs and fly every commercial mission," says Watt, thinking out loud about the longer-term perspective. "Look at the existing ground-bound precision agriculture instruments. With GPS and auto steering, a tractor is automatically guided to the end of the field and turns to the next swath, but there's still a tractor driver on board. Why? Because it's not yet acceptable to have a 300-horsepower tractor roaming the countryside. So the robotics industry is looking at a smaller, less threatening, driverless tractor with driverless followers doing the same operation. Someone in a warm cabin at the edge of the field, controlling a string of tractors, could be the next thing. It's the same with UASs: the technology is there, but perhaps we'll have to turn around a part of the concept to fit in with the health and safety regulations." ◀

JIM WATT

Jim Watt, a farmer's son and agricultural engineer, has more than 30 years of global experience in the field of agriculture and precision agriculture. He has been working with Trimble since 2002 and is due to retire as regional director EMEA in Trimble Navigation's Agriculture Division in the coming months.

CREATING A 3D LANDSCAPE MODEL OF A GRAVEL QUARRY IN GERMANY

Integrating UAS and **Multibeam Echosounder** Data

Knowing the volume of material present in a gravel quarry can make the difference between profit and loss. A gravel quarry in Hartheim am Rhein, southwest Germany, is partially covered by artificial lakes. To determine the volumes of the above-water gravel dumping grounds and to map the bottoms of the lakes, high-precision data captured by a UAS was combined with multibeam echosounder data obtained by boat. The author describes acquisition of the two types of data, how they were integrated and the benefits for the mining company.

A gravel quarry is associated with diggers, rough terrain, artificial lakes and heavy vehicle traffic. Surveying should not hinder the digging work as this would waste time and thus affect revenues. Therefore, to avoid interruptions or delays, the quarry site was captured by an unmanned aircraft system (UAS) while the lakes were mapped from a survey boat equipped with a multibeam echosounder (Figure 1). Both surveys were conducted simultaneously. Not only does the use of a UAS avoid interruptions to the digging work but it also prevents surveyors having to venture onto hillsides or slippery slopes on foot to install a levelling rod, a GNSS pole or a total station prism. It is thus a very safe surveying technology and also eliminates a considerable amount of on-site work.

SITE

The Hartheim am Rhein site, run by Knobel-Bau GmbH, is the biggest quarry site in southwest Germany. Located alongside the A5 motorway and covering 55 hectares, the quarry includes two artificial lakes both resulting from the removal of gravel (Figure 2). The lakes are flanked by trees, rocks and agricultural fields on one side and by the motorway on the other. A municipal road divides the quarry into two separate areas. On both lakes, floating dredgers excavate gravel on five to six days per week. The banks are largely inaccessible and the mined gravel is stored on two dumping grounds. There is a single access road leading to the two lakes, which are not connected. A trailer is required to move the survey boat from one lake to the other. This is a time-consuming endeavour which involves a team of three engineers in its planning and execution.

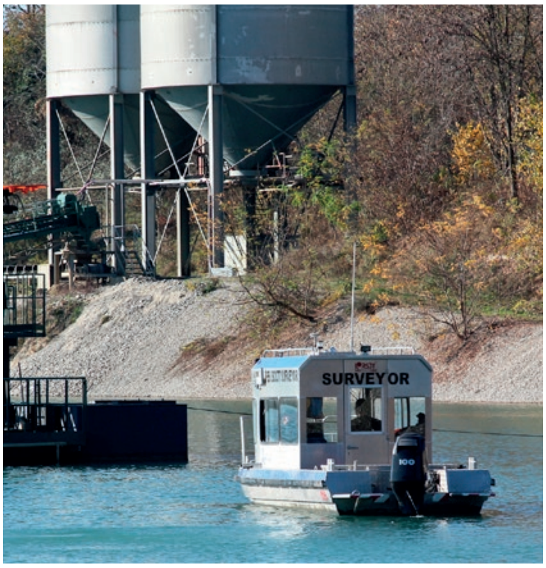
EQUIPMENT

The Aibot X6, a hexacopter with a diameter of 105cm and a height of 45cm, has an unladen weight of 3.4kg and can carry a maximum payload of 2kg. Equipped with the Nikon Coolpix A, a standard camera with a CMOS sensor and rolling shutter, the take-off weight of 4.75kg guarantees a maximum stay in the air of 15 minutes

▲ *Figure 1, Simultaneous hydrographic and air survey.*

▲ *Figure 2, The Aibot X6 in operation at the quarry site (image courtesy: Bernd Schmidt).*

under optimal conditions. The maximum speed of 40km/h makes it possible to fly over the furthest corners of the quarry within the 15 minutes of available flight time. The UAS works with a standard GNSS resulting in a precision of 2cm, which is more than enough for the present application. The flights can be conducted with or without automatic take-off and landing, position hold, point-of-interest hovering or other support functions. The navigation sensors, including GNSS, gyroscope, accelerometer, barometer, magnetometers and ultrasonic sensors, allow the Aibotix AiProFlight flight planning software to execute nearly fully autonomous flights. The gimbal supports the switching of the sensor within minutes. The survey boat, built in 2011 by Lorsby in Winsen/Aller, Germany, is equipped with a multibeam echosounder and a Leica GNSS receiver (Figure 3). The echosounder measures single depth points in grid cells of 20cm x 20cm. A total station on the ground, the Leica Nova MS60 MultiStation, captures additional measurements of terrain features.



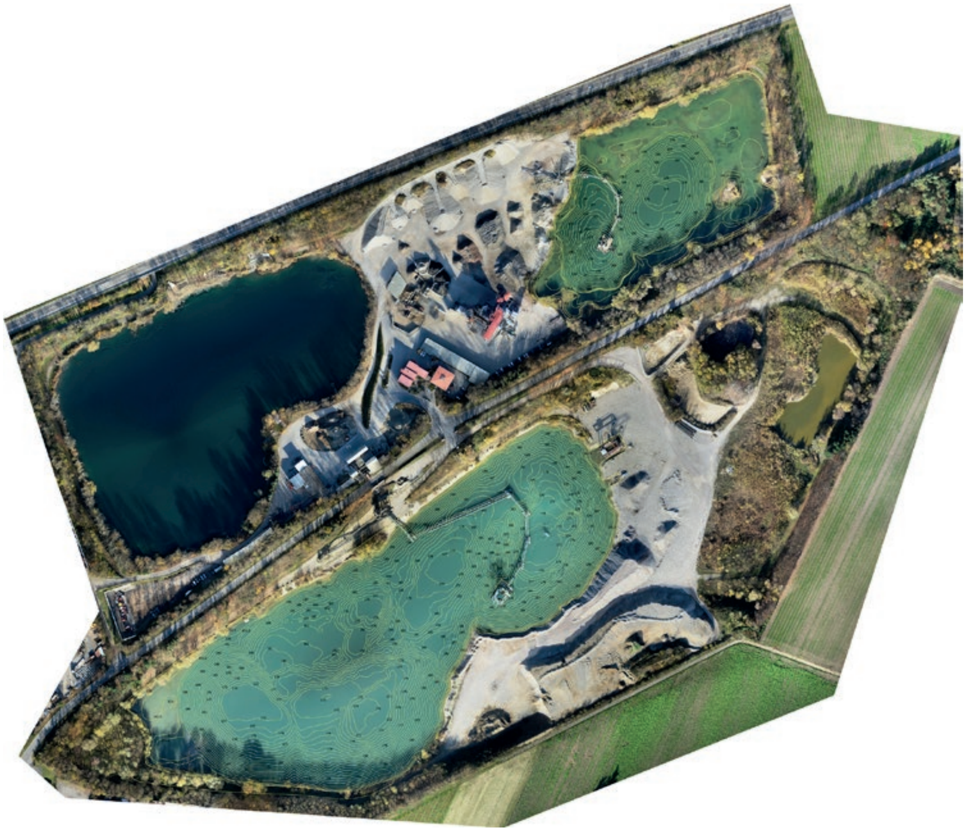
▲ *Figure 3, Survey boat.*

▲ *Figure 4, The author monitoring an autonomous UAS flight (image courtesy: Benjamin Federmann).*

LEGISLATION
In Germany, official permission is needed to fly over motorways and most cities. Legal regulations prescribe that flights have to be executed in line of sight and the pilot must be able to control the UAS manually at all times (Figure 4). To guarantee safe operation, two pilots executed the survey: one operated the UAS and the other assisted in sighting the UAS. Commercial operation of a UAS requires permission from the local aviation safety organisation and the police must also be informed. While it was easy to obtain the relevant permission, it was a challenge to plan the survey without flying over the motorway since it passes some parts of the quarry at a distance of just 10 metres.

SURVEY
Using Aibotix AiProFlight, it is possible to plan the flights both in the office and on site. The pilot can define all waypoints and the camera exposure positions using a PC or a tablet and upload the survey details wirelessly. For experienced pilots, the planning procedure only takes a few minutes. The weather during the survey in November 2015 was sunny but windy. The image capture was planned to be carried during five individual flights while flying at a height of 90m above ground, but due to the wind the decision was made to increase the number of individual flights to seven. To ensure safe flights the wind speed should not exceed 6m/s and the planned flying time should allow for a margin of 30% of the total flight time as back-up. For GNSS positioning, 10 satellites could be tracked during the flights. For georeferencing purposes, 12 ground control points were distributed over the area so as to ensure visibility from the air.

EIGHT DAYS ONLY
To create the deliverables, the data captured from the ground, water and air had to be combined. Back in the office, a digital surface model (DSM) with a grid spacing of 4cm and an orthomosaic were created from the UAS imagery using Agisoft PhotoScanPro. The georeferenced depth values acquired by the hydrographic survey were processed using Autodesk AutoCAD to generate a DSM of the lake bottoms. Next, both DSMs were combined in AutoCAD to compute volumes of the terrain features and the lakes and to generate contour lines. The



▲ *Figure 5, Orthoimage superimposed with contour lines.*

contour lines were superimposed on the orthoimages (Figure 5). The entire project took eight working days, from planning, execution of the flights and the hydrographic survey to the final volume calculation, orthoimage generation and the creation of the 3D landscape model (see Figure 6).

The orthomosaic with contour lines and the 3D landscape model provide the mining company's management team with all the information necessary for monitoring and managing the exploitation of the quarry. A DSM automatically generated from imagery may contain artefacts. Although not 100% realistic, the virtual representation of the quarry in the form of 3D landscape models has been an eye-opener for the managers as it gives them at-a-glance insights into what is on the ground and hence enables them to improve their plans and save costs. The products have also been used to update all site plans, and bimonthly or quarterly updates are envisaged for the future.

CONCLUDING REMARKS

The biggest challenges in this project were posed by the flight restrictions around the quarry, with the two lakes and the wind adding to these challenges. The combination of aerial, hydrographic and ground-based total station data made it possible to considerably reduce the costs for monitoring the quarry site. ◀

Figure 6, 3D landscape model of the quarry.

FURTHER INFORMATION

www.it-geo.de

Video: www.youtube.com/watch?v=OdFp1q__zqM

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