



Drones: applications and compliance for surveyors

May 2019



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Foreword

Drones, or to give the technology its correct moniker, unmanned aerial vehicles (UAVs) or unmanned aerial systems (UASs), are a rapidly evolving and highly adaptable form of disruptive technology. The technology has multiple potential applications within numerous surveying-related sectors, which range from geospatial surveying and mapping to scanning, building surveys, environmental monitoring and agriculture, to name just a few. This insight paper is designed to address a complex sector and to underline the critical importance of adhering to national and regional legislation and the associated regulations.

UAVs are easy to access but more challenging to use. These challenges range from adhering to the relevant jurisdiction's operating regulations, understanding the necessity for appropriate levels of training (piloting) and assessments to, importantly, providing the survey output clients expect from a professional surveyor.

Although UAVs can be used for a wide variety of survey-related applications, we also wanted to give surveyors an insight into the importance of the sensors the drones carry, and how development of these sensors will play a pivotal role in the future success of the sector. Technological miniaturisation of laser scanning equipment, such as LiDAR, and the resurgence of high accuracy photogrammetry (and its related software) have meant UAV output and accuracy can now compete with the more established technology, such as satellite imagery and manned aircraft. Yet it is important to understand not only the potential applications of UAV use, but also its limitations.

UAVs have evolved beyond the 'hype' and are now starting to become operationally viable on an expanding commercial basis. Of course, UAVs are not just for surveyor use and can be used by numerous other professions and sectors, but we are part of a broad church and believe that this insight paper provides an opportunity to understand and appreciate the potential benefits of UAV use.

We are indebted to our industry colleagues for the peer-review process and commentary that this insight paper has received, and hope you find it as interesting an area as we believe it is.

James Kavanagh

Global Land Standards Director

Glossary

3D point cloud	3D geometric information, mainly acquired through laser scanning and photographic surveying technologies. It is used for digital surface modelling (DSM), as-built building information modelling (BIM), digital elevation modelling (DEM) and digital terrain modelling (DTM).
Agronomic characteristics	Relating to the science of soil and plant characteristics.
CAP 722	Unmanned Aircraft System Operations in UK Airspace – Guidance.
CE marking	Certification mark that indicates conformity with health, safety and environmental protection standards for products sold within the European Economic Area.
Copernicus	The EU’s Earth observation programme.
Drone operator	Person or organisation who manages the drone, but is not necessarily controlling the flight.
Drone pilot	Person who operates the drone’s flight by manual use of the controls or, if the drone is flown automatically, is able to monitor its course and intervene by adjusting the flight controls.
Electronic conspicuity	Automatic identification of all airspace users, including drones.
Geofencing	Software feature using GPS to define geographical boundaries.
Geospatial data	Data that includes a direct or indirect reference to a location on Earth.
Geotagged radiometric image	Image associated with a geographical location, taken with a thermal sensor that has temperatures of individual image pixels.
Gimbal	A rigid frame acting as a pivot and allowing full rotation on a single axis.

Inertial measurement unit	Electronic device used to provide position data. It measures and reports a body's specific force and angular rate using a combination of accelerometers and gyroscopes.
Line of sight	Aircraft must be able to be seen clearly by the person flying it at all times when the aircraft is airborne.
Orthoimage mosaics	A group of orthoimages [geometrically corrected aerial imagery] stitched together to form a new composite image.
Orthorectified imagery	Aerial photography, where the scale has been corrected geometrically to take into account any optical distortions from the sensor system.
Payload	The load, usually measured in terms of weight, that is carried by the drone, e.g. a camera.
Photogrammetry	The science of generating measurements from photographic images.
Satellite	Artificial object orbiting Earth, or any other planet, for the purpose of either communication or data collection.
Small unmanned aircraft [SUA]	Any aircraft operating without a human pilot on board.
Thermographer	Individual qualified to monitor an object's temperature variations through radiation detection, either with or without visible illumination.
Unmanned aircraft system [UAS]	Whole system that includes a human-operated control base, UAV [see below] and a command and control system linking vehicle and controller.
Unmanned aerial vehicle [UAV]	Aircraft with no human pilot on board. They can be flown remotely from the ground, or autonomously by way of a pre-programmed flight plan.
Unmanned traffic management [UTM] system	Air traffic management system operating autonomously.

Acronyms and initialisms

ANO	Air Navigation Order
BEIS	Department for Business, Energy and Industrial Strategy
BVLOS	Beyond visual line of sight
CAA	Civil Aviation Authority [UK]
CASA	Civil Aviation Safety Agency
DPA	<i>Data Protection Act 2018</i>
EASA	European Aviation Safety Agency
EVLOS	Extended visual line of sight
FAA	Federal Aviation Administration [USA]
FINS	Flight information and notification system
GDPR	<i>General Data Protection Regulation</i>
GNSS	Global navigation satellite system
LiDAR	Light detection and ranging scanner
OGI	Optical gas imaging
OSC	Operating Safety Case
PfCO	Permission for Commercial Operations [UK]
SfM	Structure from motion
SUA	Small unmanned aircraft
TSC	Transport Systems Catapult
VTOL	Vertical take-off and landing

1 Introduction

The development of disruptive technologies has changed the way we live and work throughout history: the steam engine, the automobile, the personal computer, more recently the smartphone – and now the drone.

The first military use of unmanned aircraft, or air drones, dates back to 1849 when Austrian soldiers attacked the city of Venice with unmanned balloons filled with explosives¹. The term 'drone' possibly originates from the 1935 wartime aircraft called the Queen Bee, or could possibly be an acronym for dynamic remotely operated navigation equipment. Drones have been widely used in the military since the 1980s, although the past ten years has seen the use of drones for non-military purposes, with significant growth in commercial use over the last five years.

The recent drone incidents that forced the repeated closure of Gatwick airport at the end of 2018, and separate incidents at Heathrow and Newark Airport in New Jersey in early 2019, along with public concerns relating to privacy and security and terrorist use, has meant the public perception of drones has hit a definite low point. Conversely, there are predictions for considerable growth in value of the drone industry, and reports of significant benefits that drones can bring to the economy and society.

Most of us are aware of the use of drones in the military, film and television production, and surveying and mapping – and more recently tethered drones were used for broadcasting and security at the 53rd US Super Bowl. For those in the surveying profession, drones have become just 'another tool in the toolbox', but for most drone users the focus is on the sensor that the drone can carry. Sensors are now capable of producing far higher resolution and richer data than ever before. Sensor manufacturers have recognised the opportunities offered by drone technology and are working on reducing the size, weight and power requirements of their sensors to meet a suitable payload for drones.

Many industries have warmed to the potential that drones can bring. This is because these smaller aircraft platforms, operating at lower altitudes than satellites and manned aircraft, result in the democratisation of data and overcome the hurdles, such as cloud cover, faced by these more traditional platforms.

Types of sensors include ultra-high definition (UHD) video, optical cameras (red, green and blue (RGB)), thermal, LiDAR, optical gas imaging and multispectral and hyperspectral (see sections 3.1–3.7). Many of these have been through the test stages and are now accepted technologies. Impressive processing software, for example, structure from motion (SfM) photogrammetry, adds an additional benefit to these technologies.

Despite fast-moving developments, drones are still in their infancy. As the technology develops the regulatory system is playing 'catch-up' and governments are grappling to regulate the practitioners, manufacturers and systems within the industry. There is also the ever-increasing need for simplicity as the different standardisation bodies become involved to ensure the technology is fit for purpose and will integrate seamlessly into daily life.

Businesses require an understanding of the industry and its capabilities as they develop their own drone strategies and assess the potential impact the technology will have on their profession. It is inevitable that drones will impact your profession in some way – the industry is thriving and drones are likely to be here to stay, regardless of current public perception.

1.1 Types of drones

The typical drone on the market today is battery powered with propellers for propulsive power. Flights are limited in range and time by battery life, payload, line of sight, regulatory constraints and radio signal to the controller.

There are four main types of air drones:

- fixed wing (like an aeroplane)
- rotor (similar to a helicopter)
- multi-rotor
- hybrid.

In UK law drones are split into the following categories according to their weight or mass (see **CAP 722** for guidance on drone operations within UK airspace²):

- **Small unmanned aircraft (<20kg):** this class covers all types of drones including traditional remotely-controlled model aeroplanes, helicopters or gliders, as well as the increasingly popular multirotor drones and other remotely controlled ‘toy’ aircraft. They normally have a reduced level of regulation imposed on them, which is aimed at being proportionate to their risk and complexity. It should be noted that members of model aircraft associations are exempt from the requirement to ensure that direct unaided visual contact is maintained with the aircraft, provided the aircraft does not exceed 3.5kg, is flown at heights lower than 1,000ft and that first-person view is maintained.
- **Light unmanned aircraft (20kg to 150kg):** this class covers the larger and potentially more complex types of unmanned aircraft and large model aircraft. They are subject to all aspects of UK aviation law. Approval to operate outside of UK aviation law is normally given following the submission of an unmanned aircraft system (UAS) Operating Safety Case to the Civil Aviation Authority (CAA), which is essentially documentation demonstrating that the unmanned aircraft can be flown safely.
- **Unmanned aircraft >150kg:** unmanned aircraft within this class will normally be subjected to the same level of regulatory approval as traditional manned aircraft. They will normally be certificated by the European Aviation Safety Agency (EASA), although there is also scope to approve UK-only operations via the same process used for light unmanned aircraft.

This insight paper typically, although not always, relates to small unmanned aircraft (SUA), specifically air drones that are 20kg or less (including tethered drones, where the unmanned aircraft remains securely attached via a physical link to a person, the ground or an object at all times while it is flying). Most drones today have built-in safety features in the interests of public safety and national security, including:

- a range of specifications and features, such as avoidance sensors, gimbals and microprocessors (previously only available on high-end and expensive drones but increasingly available on more affordable options)

- multicopter and hybrid drones have vertical take-off and landing (VTOL) capabilities – in terms of safety a six- or eight-motor multicopter drone will usually keep flying when one, or even two, motors fail. A quadcopter (which has four motors) will fall to the ground in the event of a motor failing
- multicopter drones can hold their position in the air (assuming they have an on-board global positioning system (GPS) and/or obstacle avoidance by ground sensors), which makes them particularly useful and safe in confined areas, and in areas requiring controlled use, e.g. urban areas, infrastructure inspections.

1.2 Size of the drone industry

According to the CAA's online list of approved commercial operators of SUAs (<20kg)³, there were 359 permitted SUA operators in the UK by the middle of 2014. By September 2015 this number had jumped to 1,036; April 2016 saw an increase to 1,557; and by February 2019 there were approximately 5,000 permitted drone operators in UK airspace.

The UK's Department for Transport (DfT) has developed a chart (based on several assumptions and not to be viewed as targets or forecasts) that shows the possible extent of drone use in the UK if historical trends in commercial operator permissions continue (Figure 1). Based on these DfT predictions, there could be 16,000–17,000 commercial drone operators in the UK by 2024.

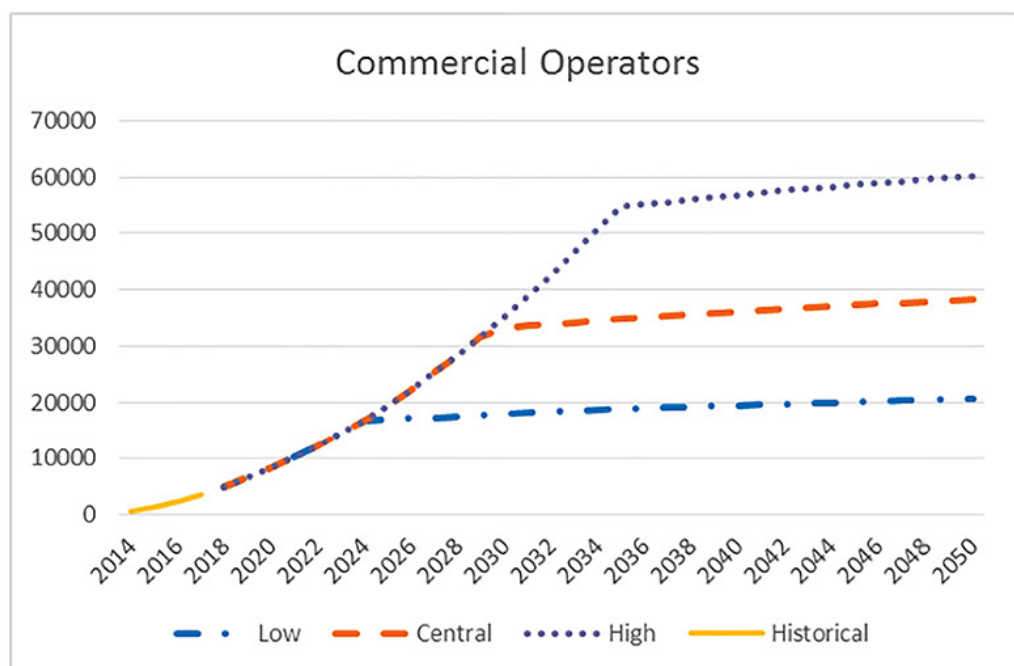


Figure 1: UK Department for Transport's predictions on the future number of commercial drone operators (source: DfT)

In addition, a recent PwC study predicts that by 2030 there could be 76,000 drones operating in UK airspace, 628,000 jobs in the drone economy and a £42 billion increase in UK gross domestic product from the drone industry.⁴

Taking cognisance of the potential offered by drones, commercial organisations are investing in research and development while collaborating with research institutes, to demonstrate new uses for drones. The number of drone-related patents has been increasing in line with this uptake. Similarly, the number of academic research papers published in recent years has seen a consistent increase over the last five years.

Links between manufacturers, practitioners, regulators, and governments involved in the drone industry have become stronger and this will provide a solid foundation for the growth of a safe, secure and fully accountable industry.

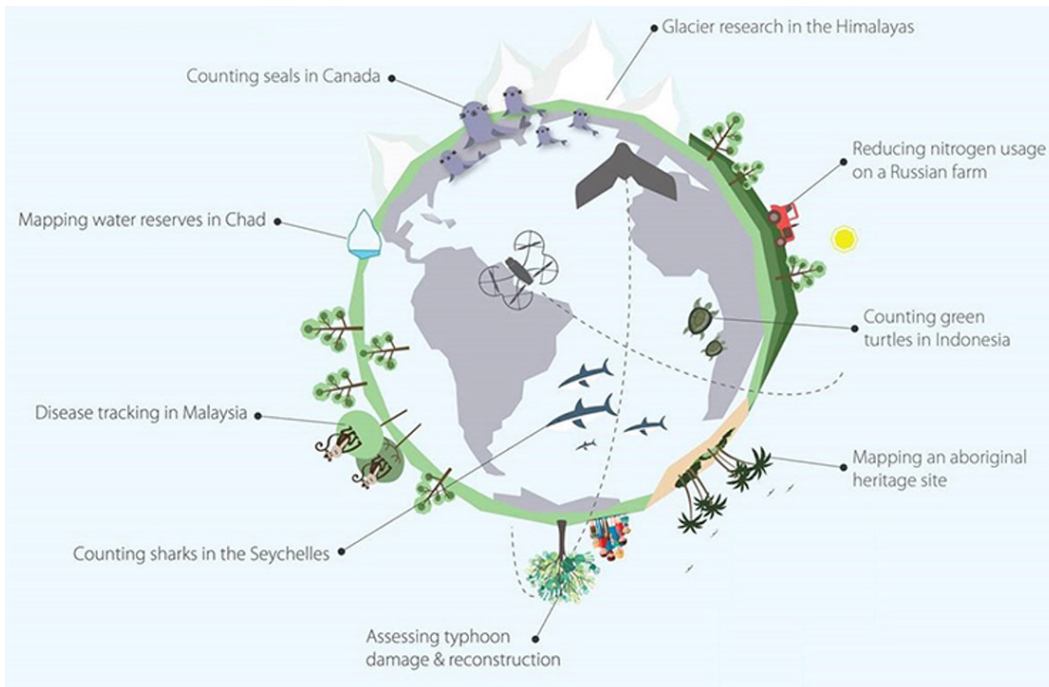


Figure 2: Beneficial drone applications around the world

2 Opportunities and challenges

Like the drone industry, satellites (the more traditional remote sensing data collection platform) have seen a significant increase in both number and range, such as the recently launched Sentinel satellites developed specifically for Copernicus, the European Union's Earth observation programme. Despite these advances, there is still limited availability of high spatial (<10m) resolution data of sufficient timescales at reasonable prices. Manned aircraft, although capable of producing data at sufficient resolution, have significant constraints, e.g. operational, safety, logistics and cost, and can also be affected by weather. Due to these restrictions they are generally only feasible for surveying medium-sized areas, i.e. areas >50 hectares.

2.1 Opportunities

The deployment of drones as data collection platforms, to service a diverse range of civilian, scientific and remote-sensing applications (see Figure 2), is an area of intensive research and development. Compared to satellites and manned aircraft, they are more flexible and adaptable, and can be flown freely (subject to suitable weather conditions).

Unlike satellites drones are not, typically, on a fixed orbit and do not have the significant mobilisation requirements of manned aircraft. In addition, they have the capability for greater temporal data and far richer spatial resolution, particularly when data is required for a small area (see Figure 3). In terms of spatial coverage, satellites and manned aircraft will always have the advantage, but drones offer remote sensing that bridges the gap between the 'boots on the ground' and satellites or manned aircraft.



Figure 3: Drone imagery (centimetre resolution per pixel) versus satellite imagery (metre resolution per pixel)

Drones are small, offer highly flexible use, are easy to handle and available at a comparatively low cost. In emergency situations, e.g. search and rescue, drones offer additional benefits in providing close to real-time information and a better understanding of the dynamics of the environment. Also, the lower costs and reduced time-frames ultimately mean improvements in site and asset management. Drone operators can also generally work around (or below) the weather restrictions, such as clouds, that limit other remote-sensing platforms.

Considering all of these advantages it is no surprise that there is intensive research and development into the use of drones across a number of domains, such as energy, safety and security, construction, mining, quarrying, oil and gas, agriculture, insurance, real estate, industry, transportation and environmental monitoring. Some universities are leading the way in innovative uses of drones, e.g. Imperial College London's water sampling drone and drones for 3D printing.

2.2 Challenges

With opportunities come challenges and there are several relating to the drone industry. Public concern in relation to privacy, security and safety issues is one of the main issues. It is hoped that these concerns will be mitigated by a regulatory framework for flying drones, manufacturing drones and data management and security. A result of introducing regulations may be over-regulation, which could inhibit the growth of the industry – so it will be important to strike the right balance from collaboration and communication between the various relevant parties.

Other challenges include the energy consumption of the drone, which can become a limiting factor in terms of flight time and payload; in some cases a task may not be feasible by drone but developments in new battery technology should offer a solution to this issue.

Geopolitical tensions may also have an impact on the future of drone technology as a number of recent incidents have resulted in restrictions being placed on technologies manufactured in different global regions.

Cybersecurity is also an issue especially if there is involvement with critical infrastructure, such as nuclear power plants or military sites, or other sensitive projects and cloud-based data storage where processing options are employed.

3 Sensors and drone innovation

A drone's flying capability and its ability to reliably carry a heavy payload are key functions, as the drone is only a toy if it is not capable of carrying a sensor or other payload, e.g. medical supplies. Table 1 shows some examples of sensors currently available, and their uses.

Drone technology is relatively affordable in comparison to the more traditional remote-sensing platforms and it enables data to be captured with a range of sensors across many applications for a relatively small investment. Drones offer high versatility, adaptability and flexibility compared with manned airborne systems or satellites, and have the potential to be rapidly and repeatedly deployed to obtain high spatial and temporal resolution data. Although the drone is the enabling technology, it is sensors that are the important technology with the power to determine the future of the drone industry.

Type of sensor	Current uses
Optical cameras (still and video)	Imagery Mapping 3D models
Optical gas imaging	Gas leak detection
Multispectral	Vegetation monitoring Crop health management
Thermal	Solar farm inspections
Hyperspectral	Vegetation monitoring Minerals mapping
Laser scanners/LiDAR	3D modelling

Table 1: Sensors and examples of their uses

3.1 Cinema/video

You may have noticed an increase in overhead film shots and distant vistas from above ground in movies. These shots are thanks to drones with appropriate stabilisation that can carry cameras of exceptional quality for producing cinema-grade footage. There are many drones available that can carry these cameras: some as integrated units, others with a gimbal capable of carrying the required payload.

3.2 Optical cameras

Drone-mounted cameras are currently being used to monitor physical assets and infrastructure, including building and bridge inspections for maintenance purposes, railways, roads, mining and oil and gas facilities. On construction sites, the use of drones has increased as the benefits of what drone data offers are realised – with the data potentially suitable for input into building information models (BIM). Drones with optical sensors can provide a useful snapshot in time to monitor construction works, and can also be beneficial for wind turbine and blade inspection. In addition, many estate agents (residential surveyors) will now include an overhead photograph, taken by drone, in the particulars of a property for sale.

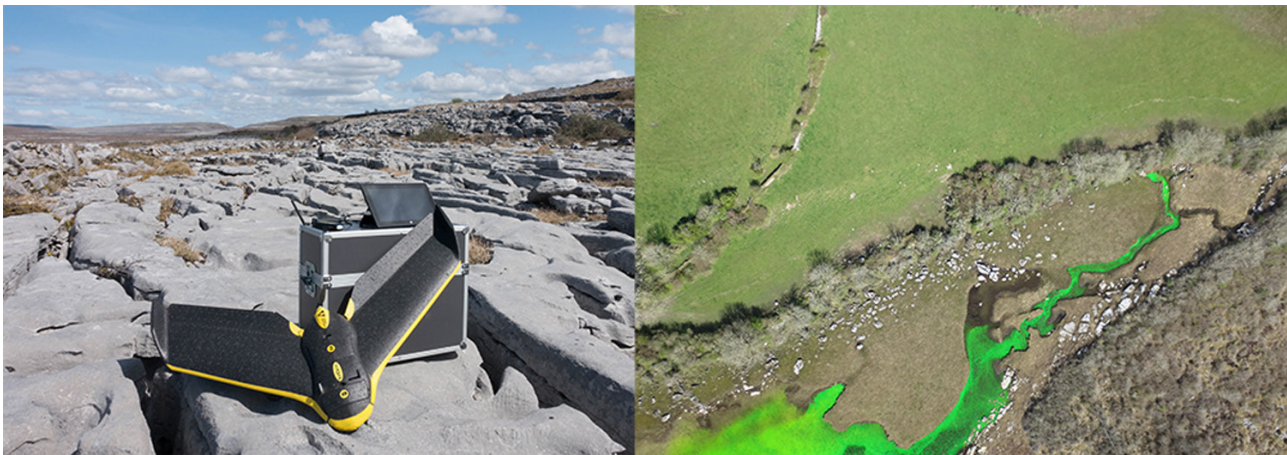


Figure 4: Fixed-wing drone used to survey a karst landscape



Figure 5: Multirotor drones used to survey high limestone cliff faces for bat roosts

Geomatics surveyors will likely be aware of the relatively new SfM photogrammetry software that enables imagery to be georeferenced and stitched together into one image. Using drone-collected data, surveyors can fly over sites of interest, with suitable overlap parameters, and produce high resolution 3D point cloud data and derived orthorectified imagery.

In recent years, SfM photogrammetry packages such as Bundler, Pix4d, and Agisoft Metashape have made it easier to produce high-quality digital elevation models and orthoimage mosaics from imagery acquired with variable orientations and overlap, and from

cameras that have not been rigorously pre-calibrated. Even consumer-grade optical cameras (RGB) can be used in the production of high-resolution orthomosaics and surface models derived from SfM techniques.

The three advantages of drones and SfM are speed, cost and resolution. It is widely anticipated that drones will start to take over from GPS, total station and laser scanners as the main survey grade data collection method as they are far more efficient at capturing geographic data, particularly over larger and more detailed sites. This will bring significant financial benefit to those companies using drone technology to collect geographic data; for example, fixed wing drones have been used to survey a karst landscape in tandem with a hydrogeological assessment. Dye-tracer tests were performed to determine the direction of ground-water flow and drone data was used to identify the location of natural discharge points (springs) for the karst aquifer system (see Figure 4). Also, in Georgia, multirotor drones have been used to survey high limestone cliff faces to find caves that may be suitable for bat roosts, as part of a proposal to construct a hydro dam and flood the limestone gorge. The bat survey formed part of the environmental impact assessment for the proposed development (see Figure 5).

SfM photogrammetry software packages are bringing photogrammetric methods to a larger user group and typically involve almost fully automated workflows. Although raw imagery acquired from small drones typically has sub-decimetre ground resolution, this high spatial resolution does not necessarily imply correspondingly-high spatial accuracies, unless rigorous workflows are followed. The quality of the global navigation satellite system (GNSS) capability of the drone has a significant influence on the data accuracy achievable. Relatively affordable drones with both real-time kinematic and post processing kinematic GPS capability may reduce or even negate the requirement for ground control points in some applications. Survey data accuracy can also be affected by the on-board inertial measurement unit (IMU), data collection parameters and site characteristics.

The *TSA Client Guide To Small Unmanned Aircraft (SUA) Surveys* states that ‘as a rule of thumb the precision, (or relative accuracy) of the drone survey after processing, is known to be within the order of 1–2 pixels in plan and 2–3 pixels in height’.⁵ Using this principle, if the ground sampling distance of a survey is 40mm the accuracy could be assumed to be approximately 40–80mm in plan and 80–120mm in height.

Geomatic surveyors will need to consider a number of parameters before producing suitable mapping from a drone survey, such as flight planning, area to cover, required image overlap (lateral and longitudinal), and the use and distribution of ground control, as these considerations will have a significant influence on the quality of the end product.

3.3 Thermal

Thermal or heat detection sensors are easy to use, and the data images collected straightforward to understand. However, depending on the end use, a qualified thermographer may be required to interpret the results as they will understand the thermal radiation spectrum.

There are two types of thermal data: radiometric and non-radiometric. Radiometric data means that a specific temperature is provided for each pixel or point of data; non-radiometric data shows more general temperature differences and changes in an area.

Some examples of thermal sensor use include utility inspections (power lines, chimney stacks, water works, telecoms masts, substations), solar farm inspections, construction site and roofing inspections, fire-fighting, search and rescue, and land contamination monitoring (e.g. mining, landfills).

Geotagged radiometric images can be processed in SfM photogrammetry software to produce an orthorectified stitched thermal image. Aerial differential infrared thermography can be carried out to improve a thermal assessment of an asset. This is carried out by performing two measurements of the same region at two different environment temperatures (e.g. sunrise and sunset) and comparing the results.

3.4 LiDAR

Airborne laser scanning is a technology used for topographical surveying and mapping, e.g. hydrological mapping, construction and forestry. This method employs a light detection and ranging (LiDAR) scanner and is based on time of flight measurements of emitted laser pulses from surfaces on or near ground, measuring the distance to the object from the sensor. The main output from a LiDAR survey is a 3D point cloud. The purpose of the survey, and the required density of the point cloud will determine the specification of the sensor. LiDAR surveys are capable of mapping extremely narrow objects, such as overhead electricity lines, subject to the resolution employed.

3.5 Optical gas imaging

Optical gas imaging (OGI) cameras can pinpoint gas leaks invisible to the naked eye. With an OGI camera it is easy to continuously scan installations in areas that are remote or difficult to access.

OGI cameras are widely used in industrial settings, such as oil refineries, natural gas processing plants, offshore platforms, chemical/petrochemical complexes, and biogas and power generation plants.

3.6 Multispectral

The human eye is only sensitive to wavelengths between 400nm and 700nm, which is known as the visible RGB spectrum. Multispectral camera remote sensing imaging technology uses green, red, and near-infrared wavebands to capture both visible and invisible images. Multispectral remote sensing is widely used in agriculture and for environmental monitoring purposes, typically for assessing soil or vegetation health. Figure 6 shows examples of multispectral, thermal and RGB data images from a mine tailings facility. The data was used to assess the tailings dam for seepages and/or contamination issues.

Viewing the health of soil and crops with the naked eye is very limited. Multispectral imaging allows for the extraction of additional information the human eye fails to capture and is a very effective tool for evaluating the agronomic characteristics of soil, plants and crops. Besides vegetation indices for evaluating green biomass, multispectral images can be formulated to other spectral indices targeting senescence evaluation, nutrient status, pigment degradation, photosynthetic efficiency, or water content.

Multispectral data are typically processed using SfM photogrammetry software.

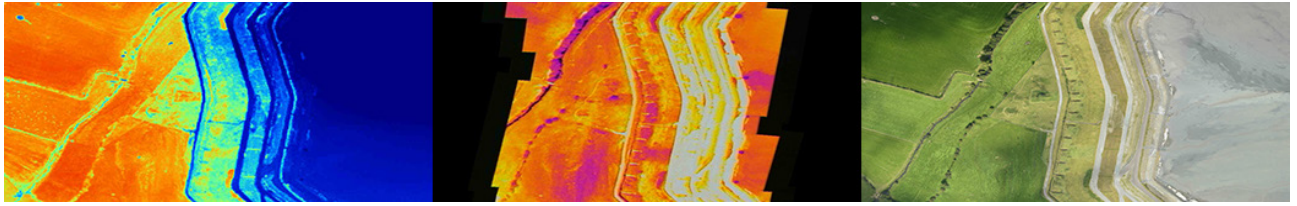


Figure 6: Multispectral, thermal and RGB data from a mine tailings facility

3.7 Hyperspectral

The main difference between multispectral and hyperspectral sensors is the number (and narrowness) of bands used. A hyperspectral image can have hundreds or thousands of bands, offering better capability to see what the human eye cannot.

Hyperspectral sensors are being used in mineral mapping, land contamination monitoring, agriculture, ecology, oil and gas, oceanography and atmospheric studies.

4 Potential uses of drones

The commercial use of drones continues to gain momentum – aided by a decrease in costs and an increase in the reliability of the technology.

As the software is developed to integrate with the drone hardware, uptake across individual operators and large organisations is set to increase; with software options for processing drone data including licensed, cloud-based and open source.

The development of standardisations and the evolution of regulations in drone technology (e.g. flight planning and geofencing) will result in the use of drones becoming increasingly widespread, efficient and reliable. Advances in automated processes for flying and data collection will see the more risk-averse user adopt drone technologies in existing workflows. Advances in artificial intelligence and machine-based learning will see automated approaches to analysing gigabytes of imagery data, which will be particularly useful for infrastructure inspection.

Drones and associated workflows will be packaged as a complete solution (some already are), and comply with standards in manufacturing, pilot competency, safety and regulation through to automated data capture, and approved methodologies for data collection and analysis. Ongoing developments in regulation will ensure safety, security and accountability.

Eventually, drones will be used for everyday tasks such as fertilising fields, monitoring traffic in urban areas, delivering packages to remote rural regions, express deliveries in urban areas, and emergency medical deliveries, e.g. defibrillators, bloods. NHS Highland is currently working with Highlands and Islands Enterprise and the University of the Highlands and Islands on a project that could see drones pick up and deliver medical items across its regions.

In some cities, where drones are faster for deliveries than current transport methods, this may offer an additional advantage of a reduction in carbon dioxide emissions.

Research is currently being carried out into using drones for taking water samples from lakes and rivers, carrying passengers, taking air samples from volcanoes (see below), and using drones for 3D printing. Perhaps we will even see drones being used to clean the windows of the world's tallest buildings in the not-too-distant future?

4.1 Use of drones in urban environments

Nesta, a global innovation foundation, has prepared a report from their Flying High Challenge.⁶ The project explored the current and future possibilities for the use of drones in urban environments through engagement with five UK areas (Bradford, London, Preston, Southampton and West Midlands), national level institutions and policy and technology experts. The project explored the following five socially beneficial uses of drones and the technical, social and economic aspects of each:

- medical delivery in London
- traffic incident response in the West Midlands
- Southampton to Isle of Wight medical deliveries

- construction and regeneration in Preston
- supporting the fire and rescue service in Bradford.

4.2 Environmental monitoring

Imaging spectroscopy, using spectral libraries, has been developed as a reliable technique for quick mineralogical analysis of mine wastes, which saves both time and costs versus conventional sample collection. Traditional data collection methods involved sensors mounted on satellites (20–30m resolution) and manned aircraft (2–10m spatial: 10–20nm spectral resolution). However, smaller and lighter hyperspectral sensors are now being mounted on UAVs allowing hyperspectral data to be collected at a higher temporal and spatial resolution.

There are obvious benefits of using UAV-mounted hyperspectral sensors for monitoring a range of environments, for example, to monitor mine sites and contaminated land. There are also definite benefits in this technology for mine rehabilitation works as it provides an invaluable tool for environmental evaluation and change analysis. In isolation, however, hyperspectral data is not enough – but when used along with other monitoring methodologies, and calibrated correctly, it provides very useful information for a variety of end uses.

4.3 Humanitarian and sustainable development

Humanitarian aid and sustainable development involves dealing with many complex challenges, including fast-changing environments, extreme weather events, climate change effects, and high-risk environments. There are significant advantages to using drones to assist humanitarian aid efforts, development and peacekeeping operations, for example, delivering emergency supplies (e.g. food, medicine) to isolated areas that may be inaccessible by road; gathering up-to-date geospatial data (e.g. for areas affected by earthquakes, landslides); and search and rescue or damage assessment.

The United Nations Children's Fund (UNICEF) and the World Food Programme (WFP) have formed a working group to extend the use of drones for humanitarian work. Similarly, the World Bank Group (one of the largest sources of funding and knowledge for developing countries) is harnessing the potential of using drones to support development operations and is currently relying on drone technology for post-disaster damage assessment, infrastructure management, and risk assessment. The company has identified the potential for drone use to assist in Internet connectivity in rural areas (through a perpetually airborne network of drones), meteorology (using reusable airborne weather sensors), and firefighting.

4.4 Monitoring of volcanoes

The amount of gas emitted from a volcano during a specific time-period is directly related to the volume of magma that sits in the subsurface reservoir. Measuring the rate at which a volcano releases gas or degasses allows geoscientists to determine what is happening below the surface. Changes in gases, such as sulphur dioxide and carbon dioxide, are important as they can be indicative of activity occurring in the volcano's magma reservoir and hydrothermal system. Researchers use the ratio of these two gases to determine how close the magma is to reaching the earth's surface, and how imminent an eruption may be.

Emission rates can be measured either from the ground, from an aircraft or by space observations (e.g. the Copernicus Atmosphere Monitoring Service). Safer measurement

techniques of high-altitude plumes of risky volcanoes are needed, however, and engineers and volcanologists from the University of Bristol and University of Cambridge have recently used drones to take measurements from inside volcanic clouds in Guatemala.

5 Drone regulations

The aviation industry is renowned for its dedication to safety, to the extent that other high-risk and safety-conscious industries, such as medicine and nuclear, are now using safety methods developed by the aviation industry.

In the UK, the Civil Aviation Authority's (CAA) stated primary aim is to enable the full and safe integration of all drone operations into the total aviation system, and the regulations are being developed to achieve this.

Currently the drone industry is regulated under the Air Navigation Order (ANO) 2016 and the Air Navigation (Amendment) Order 2018. Some of the provisions in the Amendment Order came into force on 30 July 2018 with more provisions due to come into force on 30 November 2019. All drones must be used in accordance with the rules set out in the ANO and CAP 722.

The ANO regulates air navigation, so indoor use of drones or flights within buildings or areas where the unmanned aircraft cannot escape into the open air are not subject to this air legislation.

The UK regulators are in 'catch up' mode with the rapid evolution of the drone industry and the government intends to bring forward a new draft Drones Bill in 2019. The government ran a consultation in 2018 to receive feedback on proposals to develop policy and regulation surrounding the use of drones and to set out the next steps needed to ensure safety, security and accountability of the drone industry.

5.1 General aviation rules

Surveyors need to have a familiarity with the current drone regulatory environment and the requirements of using drones or drone-collected data.

These requirements include general aviation rules that apply to everyone, regardless of whether they are flying a drone or not, including:

- a person must not recklessly or negligently act in a manner likely to endanger an aircraft, or any person in an aircraft, and
- a person must not cause or permit an aircraft to endanger person or property.

These offences can lead to a five-year prison sentence, an unlimited fine or both.

Under the *Aviation and Maritime Security Act 1990*, intentional use of a device to commit an act of violence at an international airport that causes or is likely to cause death, serious personal injury and endanger safe operations could result in a penalty of life imprisonment.

Drone pilots that collect personal data must comply with the *Data Protection Act 2018* (DPA), unless a relevant exemption applies. The requirements of the DPA are overseen by the Information Commissioner's Office (ICO) which can take enforcement action against people who breach the DPA by requiring them to change practices, impose fines or by prosecution for unlawfully obtaining or accessing personal data.

The CAA has been running a Dronesafe campaign and produced The Drone Code to help to raise awareness of these rules and regulations among the general public.⁷

Drone-specific aviation rules, relevant to all drone pilots (hobbyists and commercial users) include:

- small drone pilots must maintain direct, unaided visual contact with their drone
- the drone may only be flown if the remote pilot is satisfied that the flight can be safely made
- during take-off and landing, a remote pilot must not fly the SUA within 30m of another person
- the small drone pilot must not allow any article or animal to be dropped from the drone as to endanger persons or property
- all drones are restricted from flying above 400ft across the UK and within 5km (since March 2019) around protected aerodromes when air traffic control is operating.⁸ (Note that the aviation industry refers to height in feet and distance in metres.)

If the drone is equipped with a camera:

- it must not be flown within 50m of persons or buildings
- it must also not be flown within 150m of densely populated areas.

From 30th November 2019, it will be a legal requirement, before flying a drone of 250g–20kg in mass, for all drone operators to register, and for drone pilots to complete, an online pilot competency test.

5.1.1 General Data Protection Regulation (GDPR)

On 25 May 2018 the GDPR came into force. If a person can be identified or is identifiable by drone-collected information, then it is considered personal data. All drone operators need to be aware of their responsibilities under the GDPR.

Recommended good practice in relation to data protection includes:

- preparing a privacy code of conduct
- a pre-flight checklist
- carrying out a privacy impact assessment.

5.2 Commercial regulations

Commercial users of drones can operate drones outside of general aviation rules – but only once CAA permission is granted to do so on the basis of meeting strict safety conditions. You must have a Permission for Commercial Operations (PfCO) issued by the CAA before you conduct any commercial drone operations.

If you wish to conduct a commercial operation (see definition) with your aircraft or if you wish to fly your aircraft outside the limits specified above you will need permission from the CAA. An exemption from the CAA is required if you wish to seek release from any other requirement within ANO 2016. Permissions and/or exemptions are valid for up to 12 months and are subject to an annual renewal.

The term ‘commercial operations’ allows a broad variety of flight applications, which are mostly based around aerial photography or the operation of sensors and other data-gathering devices.

Commercial operations are defined within the ANO as:

‘any flight by a small unmanned aircraft except a flight for public transport, or any operation of any other aircraft except an operation for public transport;

- a which is available to the public; or*
- b which, when not made available to the public,*
 - i in the case of a flight by a small unmanned aircraft, is performed under a contract between the SUA operator and a customer, where the latter has no control over the remote pilot; or*
 - ii in any other case, is performed under a contract between an operator and a customer, where the latter has no control over the operator,*

in return for remuneration or other valuable consideration.’

The key elements in determining commercial operations are ‘... any flight by a small unmanned aircraft ... in return for remuneration or other valuable consideration’. The term ‘available to the public’ should be interpreted as being a service or commodity that any member of the public can make use of, or actively choose to use (because it has been advertised or offered to someone).

5.2.1 Permissions for commercial work involving small drones

To operate a drone commercially, the key requirement is the CAA’s Permission for Commercial Operations (PfCO). There are two types of permission available: a standard permission and a non-standard permission.

The standard permission: this enables a person to conduct commercial operations with a SUA (drone) and also permits operations within a congested area. Potential operators are required to provide evidence of pilot competence (demonstrate a sufficient understanding of aviation theory in airmanship, airspace, aviation law and good flying practice), pass a practical flight assessment (flight test) and prepare an operations manual, which details basic procedures for how the flights will be conducted. The CAA does not organise or run assessment courses – commercial organisations, known as National Qualified Entities (NQEs) organise this assessment on their behalf.

A non-standard permission: this covers all other types of flight and addresses operations that contain a greater element of operating risk, e.g. extended visual line of sight (EVLOS) and beyond visual line of sight (BVLOS), flights within 150m of organised open-air assemblies and flights within 50m of uninvolved people/properties.

In addition to the requirements for a standard permission, applicants are also required to prepare and submit an Operating Safety Case (OSC) to demonstrate that the intended operation is appropriately safe to the CAA. Tethered UAS are subject to the same basic operating regulations as all other unmanned aircraft and, where necessary, are subject to the same approvals process. However, the fact that the operation is tethered can be used as a significant mitigation factor when applying for an operating approval, thus greatly simplifying the overall process.

5.2.2 Other rules and regulations

CAA permissions and exemptions only authorise the commercial use of a drone from a safety perspective. Drone practitioners will also need to abide by any other rules and regulations imposed by other bodies and organisations. These may include the emergency services, road maintenance organisations and local authorities. Before beginning a job in a particular location, a permission holder should always check with all relevant bodies to establish if any other restrictions apply. Operators should also be sure they understand the rules around trespass and nuisance.

Details are available in guidance document CAP 722,² including the requirements for remote pilot competence.

5.3 Jurisdiction-specific legislation

Australia

Australia have taken a slightly less onerous route than other countries to regularising commercial drone operations. If the drone weighs less than 2kg it can be operated in the 'excluded' category. This requires notifying the Civil Aviation Safety Agency (CASA) before you fly and operating within certain parameters, e.g. below 400ft, during daytime only, and within visual line of sight. Operations beyond these limits, or if your drone weighs more than 2kg, require a licence or for the operator to be certified to fly. This requires training and preparation of an operations manual and an interview with CASA.

Singapore

For drone operations that are non-recreational or non-research in nature then, regardless of the weight of the drone or the location of operations, an Operator Permit and Class 1 Activity Permit will be required. An assessment is carried out to ensure the operator, equipment and personnel flying the drone are fit and capable of conducting operations safely. A physical flight demonstration may also be required.

UK

The UK government's Pathfinder Programme is part of a wider programme of work across the UK's public and private sectors, aimed at enabling integration of drones into UK airspace. The programme falls under the governance of the Department for Transport, the Department for Business, Energy and Industrial Strategy (BEIS), the CAA and the Transport Systems Catapult (TSC). The aim is to rapidly drive progress in drone technology and regulation over the next ten years, enabling both industry and the public sector to fully exploit the drone market in areas such as geo-mapping, infrastructure inspections, surveying and logistics to both commercial and public-sector industries.

USA

There are two federal laws that regulate drone technology, along with state and local laws: Section 336 of the Federal Aviation Administration (FAA) Modernization and Reform Act of 2012 and Part 107 of the FAA's final rule for Operation and Certification of Small Unmanned Aircraft Systems.

Section 336 relates to recreational use of drones (weighing over 55lbs). For commercial users of drones Part 107 is relevant. Prior to implementation of Part 107 in 2016, commercial drone users required a full commercial pilots licence to operate. Restrictions to drone flights under Part 107 are similar to the UK and require operations to be carried out within line of sight, below the 400ft flight height ceiling and only during daylight hours. Passing a knowledge test is a requirement under Part 107.

5.4 Future rules and regulations

There is considerable regulatory activity among legislators, not just in the UK, but also in Europe. These will address not just how drones are flown, but will also regulate product standards, electronic conspicuity (which will allow the automatic identification of all airspace users including drones) and geofencing (where a drone can be automatically prevented from flying within protected areas through in-built software).

The UK government is currently working with drone manufacturers to introduce these new technologies along with continuing to develop policy relating to a flight information and notification system (FINS) as part of future unmanned traffic management (UTM) and airspace modernisation programmes to ensure that all aircraft use airspace safely and securely and in accordance with the rules. The government has decided not to mandate the use of a FINS at this time, but will nevertheless continue to develop the policy as part of wider aviation strategies, including a UTM system. This will be achieved by promoting the use of current drone information applications and developing best practice guidelines to encourage their use and improve consistency of data.

There has been debate about whether the final Drones Bill will include police powers relating to drones and fixed penalty notices, a minimum age limit for the drone operator – who is not necessarily the drone pilot (see Glossary) – and no age limit for the drone pilot.

The government is also expediting detailed policy work to develop an appropriate legal framework that will allow for the testing and use of counter-drone technology that detects and/or 'affects' drones in the UK and technology that could be used to protect sensitive national infrastructure from possible malicious drone incursions in the future.

There have also been some developments at European level. In accordance with the new basic regulation (EU 2018/1139), for which a political agreement between the European Council, the European Commission and the European Parliament was reached on 22 December 2017, the competence of the EU has been extended to cover the regulation of all civil unmanned aircraft systems (drones), regardless of their maximum take-off masses. The proposed regulations will provide flexibility to member states, mainly by allowing them to create zones within their territories where the use of air drones would be prohibited, limited or, in some cases, facilitated. Pursuant to the new basic regulation (EU 2018/1139), market product legislation (CE marking) ensures compliance with the technical requirements for mass-produced drones operated in the open category.

The open category is one of three main categories being proposed by the EU in terms of operating a UAS in Europe:

- **open category** does not require a prior authorisation by the competent authority or a declaration by the UAS operator, despite the risks involved
- **specific category** requires an authorisation by the competent authority before the operation takes place, taking into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios where a declaration by the operator is sufficient or when the operator holds a light UAS operator certificate (LUC) with the appropriate privileges, and
- **certified category** requires the certification of the UAS, a licensed remote pilot and an operator approved by the competent authority, in order to ensure an appropriate level of safety.

As the industry evolves and technology and standards improve there may be a relaxation to the current drone flight limitations (i.e. 500m distance and 400ft flight height from the drone operator), as these are significant constraints to drone usage – and offer an advantage to other data collection methods (manned aircraft).

With the development of standards in drone technology (e.g. flight planning, geo fencing, collision avoidance systems) along with the evolution of the regulations, drone use will continue to become more widespread and efficient. We may even see changes to airspace to allow drone usage in certain areas, or the provision of drone corridors. There are ongoing tests being carried out into BVLOS, remote identification and obstacle avoidance technologies that will ensure automated drones can operate safely.

5.5 Standards

As new technology develops, new standards are required to help regulate the drone industry. There are currently a number of standards in development.

- The British Standards Institute (BSi) is working on standards for the 'qualification and approval of UAS operatives' and the 'registration and identification' of UAS or drones.
- In Europe, standards are being developed for product requirements and verification, remote identification, geo-awareness and lighting requirements.
- The International Organization for Standardization (ISO) have several active work programmes including terminology, categorisation and classifications, product manufacturing and maintenance, operations and procedures, and unmanned traffic management.

6 Using drones in your business

- 1** If you plan to use a drone for a relatively simple purpose using a tried and tested drone and data collection methodology, then it is relatively straightforward and affordable to get up and flying (approximately £1,500–£2,000).
- 2** Before you choose your drone:
 - a** find out what maintenance will be necessary
 - b** ascertain how many motors you require and how long they will last
 - c** check the battery shelf-life
 - d** find out the cost of replacing batteries
 - e** check the drone's safety features, and whether it has GPS, a return-to-home function and if geofencing is provided
 - f** check what wind speed the drone can fly in
 - g** ensure there is a warranty.
- 3** If you are using a drone for commercial use in the UK (see section 5.2) you will need to complete the required ground school training and tests, and obtain a PfCO from the CAA.
- 4** If you want to achieve more advanced results, such as produce orthorectified imagery and 3D data, thermal or multispectral data, you may need to gain a further qualification or training (e.g. geomatics, thermography) and purchase additional processing software.
- 5** You may also start producing large datasets that may require additional digital storage hardware or if using cloud-based software or storage, you will need access to a high-speed internet connection.
- 6** If you are going to buy your own drone and obtain your PfCO from the CAA then make sure you maintain a certain level of pilot competency by flying regularly (at least 2 hours per quarter). You will need to ensure you have the commercial business pipeline to maintain this.
- 7** If you will be flying the drone mostly in rural areas, a standard CAA PfCO permission will be sufficient, but if you are proposing to fly in urban areas you may have to prepare an OSC and comply with a more stringent regulatory route.
- 8** Ascertain how many employees will be flying the drone. Depending on your business it may make sense to have a number of people trained in operating the drone or to train just one person if you are not using the drone regularly.
- 9** Check hidden costs. These generally relate to the regulatory requirements, insurance costs, additional computer hardware for data storage and processing, along with ongoing maintenance costs and time inputs.

- 10** Ultimately drones are aircrafts offering significant potential for businesses but they also need responsible risk management. You need to ask yourself at the outset, 'How do I minimise the risk to my business and manage liability (before something goes wrong)?'
- 11** It may not make sense to have an in-house capability and instead use external contractors. Alternatively, a hybrid business model may be preferable where the more straightforward drone requirements are carried out in-house and external experts are used for more advanced requirements.

7 Conclusion

Drones have a long history, but it is only relatively recently that their commercial potential has been recognised offering significant benefits and opportunities to businesses around the world.

The technology (drones and sensors) and associated software (flight planning, data analysis), infrastructure (unmanned traffic management (UTM)), regulations and standards are continually evolving, with collaborative research and development across all these areas. The key to drone integration into day-to-day living will be the development of an ecosystem that ensures safety, reliability and accountability. Development of this ecosystem is rapidly expanding through improved technologies and a stronger regulatory environment.

If planning to use drones in the future, then this is an area with many moving parts that requires dedicated focus. Keep abreast of changes to the regulations, improvements in technology (hardware, software and firmware) and advances in data collection methodologies and analysis.

As the industry continues to grow the ‘drones for good’ story needs to be highlighted to the public to ensure full appreciation of the benefits – not just to the surveying profession, but to society as a whole. Public buy-in will be essential if the drone industry is to reach its full potential. There is, however, an onus on commercial drone operators to act responsibly and ensure compliance with all regulations.

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