Drones for GIS – Best Practice

Royal Society for the Protection of Birds
Conservation Data Management Unit (dataunit@rspb.org.uk)
Lead Authors: Adrian Hughes & Emma Teuten

Contributors: Thomas Starnes, Neil Cowie, Tom Swinfield, Richard Humpidge, Jon Williams, Damon Bridge, Colin Casey, Andrew Asque & David Morris

Version 2.0 - 30/03/2020

Image source: Pixabay

Contents

Introduction

Drones (also known as unmanned aerial vehicles, UAVs, or remotely piloted vehicles) are being used increasingly across the organisation, both on and off reserves. In many cases, the objectives for drone use requires the imagery to be mapped in Geographical Information Systems (GIS). Uses for the data in GIS include bespoke, on–demand, high resolution aerial imagery, habitat surveys, and bird colony monitoring. Often many individual drone images are joined together to create a composite image, covering a larger area. This document aims to provide best practice guidance for collecting drone imagery for use in GIS, to aid conservation practices across the organisation.

Aerial images for visualisation and analysis are a powerful tool for understanding land use changes on RSPB reserves and other areas of interest. For aerial imagery we currently rely on organisations such as Ordnance Survey and the Environment Agency to provide data. These images are scheduled to be updated on up to 5-year cycles, but updates can be less frequent. The length of these cycles, and the cost of ad-hoc flying, mean that these data are of quite limited use for assessing land cover change rapidly and continuously. Drones provide a cost-effective and rapid way to produce these data.

Best practice advice will be given on the current options available, for the firmware and other devices needed to operate a flight, and to process images. Basic safety and tips for operation will also be given but the main focus of the document will be on how you can best use drones to obtain imagery for use in GIS applications. This document should always be used in conjunction with the Code of Practice document, RSPB code of practice B09.

It should be noted that Drone hardware and firmware, along with the licensing laws associated with operation, are changing rapidly. This document will need to be updated regularly, as will the Code of Practice.

For any unfamiliar terminology, see the Glossary in Appendix III.

Licensing and Legal Issues

RSPB has a Code of Practice (RSPB code of practice B09), which covers a range of practical issues related to drone operation, including licensing, legal issues, non-commercial use of data, safety, insurance and training. For additional information, please also reference the Civil Aviation Authority (CAA) guidance. The UK Government and the CAA have made a website for Drone users http://dronesafe.uk giving details of the current Code of Practice. From November 2019, all drones are required to have a registered operator who is accountable for the drone, and all drone pilots must pass a free on-line competency test at https://register-drones.caa.co.uk/.

Hardware

Drones

There are two main types of drone on the market - multirotor and fixed wing. For the purposes of mapping and GIS, there are several commercially available products which are suitable off-the-shelf. There is also the option to use a more bespoke models which can be customised e.g. to carry additional sensors. Finally, there is the option to build your own drone.

There are some trade-offs to consider when deciding which drone to use for GIS applications. These include:

1. Reliability vs. adaptability. This hinges on your confidence in your ability to customise your drone. Off-the-shelf units should work straight out of the box, but they don't usually offer much in the way of customisation or expansion. On the other hand drones targeted at hobbyists and enthusiasts usually take more skill to get going, but are much more adaptable with the right expertise. Based on first hand experience, though, customisable drones have greater potential to malfunction in the field. This may be down to user error rather than the hardware per se, but is potentially problematic nonetheless.
2. Ease of use vs. ground coverage. Multi rotor units such as quadcopters are easier to master, but they have a more limited range so they can only survey smaller areas on a single battery; thus covering larger areas requires more flights to be made. Conversely, fixed wing drones require greater skill to fly, as well as take-off and landing strips, but they can cover much greater areas in a single flight.
3. Cost. Off-the-shelf fixed wing systems tend to be more expensive than their multi rotor equivalents, but fixed wing systems can potentially be built very cheaply with the appropriate technical expertise.

GPS-enabled cameras, which now come as standard on many consumer grade drones including most of DJI's models, automatically write latitude, longitude and altitude to the photograph metadata. The resulting images can be imported directly into a photogrammetry application for processing.

There are various other features to consider when deciding on a drone. Many of these are discussed under Operational Advice.

For a technical comparison of drone specifications, see https://www.thedronechart.com/.

Multirotor

Quadcopters offer the simplest and, by extension, the safest means of getting off the ground. This is the typical type of drone being flown by amateurs, but recent advances have made these drones suitable for many professional applications.

DJI have captured the market in recent years, most notably with the Phantom series of drones.

DJI Phantom Series

DJI Phantom drones combined durability with affordability, resulting in ideal drones for conservation purposes. Unfortunately, in 2019 the Phantom series was discontinued. As of March 2020, it is still possible to buy Phantom drones through unofficial channels.

The Phantom 3 Pro is the cheapest Phantom drone meeting the minimum technical specifications for mapping. Models released since the Phantom 3 Pro have included GPS in their factory-installed cameras, which makes them more suitable to mapping applications.

The Phantom 4 includes improvements over the Phantom 3, including an increase of the maximum flight time from 25 to 30 minutes and increase in the maximum image size from 12 MP to 20 MP. The Phantom 4 comes with an added obstacle sensing feature which is not present in the Phantom 3.

The Phantom 4 Pro also includes a built-in screen on the remote control, although unfortunately it cannot be used for mission planning. A smart device is still recommended if you plan to collect data for GIS. Compared with the regular Phantom 4, P4 Pro’s camera has a higher sensor resolution (4x) allowing higher resolution images, and it has a longer lasting battery.

DJI Phantom 4 drone. Image source: DJI (https://www.dji.com/phantom-4)

DJI Mavic Series

Following DJI's decision to discontinue the Phantom series, they recommend Phantom users switch to the Mavic 2 Pro. The Mavic drones are smaller and cheaper than Phantom drones. They can fold down enough to fit in a small rucksack. The Mavic 2 Pro's maximum wind speed resistance is 18 - 24mph, which is the same as that of the Inspire and Phantom 4. There have been some reports that the Mavic Pro can be difficult to control in high winds when the battery is low. It is otherwise a good choice for its mobility and mapping capability. Images taken in flight by the Mavic 2 Pro are of higher quality than the Phantom 3.

Because of its small size, it can be difficult to maintain a visual line of sight to the drone. Despite having a high transmitting distance (4km at 2.4GHz), CAA guidelines state that visual contact with the drone must be maintained at all times and it would be virtually impossible to see the drone at any distance greater than 1km, even with a 'spotter'.

DJI Mavic Pro drone. Image source: DJI (https://store.dji.com/product/mavic-pro)

DJI Inspire Series

The DJI Inspire drones are both larger and considerably more expensive than the Phantom or Mavic drones. By way of a weight comparison, the Inspire 2 weighs in at 3.4kg (without gimbal and camera) as compared to the Phantom 4's 1.4kg. The main advantage of the Inspire is that it can carry a larger payload than the Phantom, making it a good choice for carrying additional monitoring equipment.

The Inspire has several additional features, such as a front mounted camera which allows you to see straight ahead on the video linkup without the airframe being visible in-frame. However this is generally not an issue when taking nadir images (facing directly downwards, as required for most survey methods). GPS-enabled remote control allows the drone to use autopilot to return to home (RTH) to the controller (who may have moved, e.g. on a moving boat) rather than to the initial starting location.

The Inspire is often cited for it’s wind stability and image quality, but the official wind resistance of the Inspire is equal to that of the Mavic 2 Pro (18 - 24mph).

Yuneec H520

While DJI has dominated the multicopter drone market in recent years, the popularity of Yuneec models is growing, in particular with emergency services. The Yuneec H520 is a hexacopter drone. The extra propellers give greater stability, and provide redundancy. If one of the propellers fails, the drone will not crash out of the sky. While selection of cameras are available, the E90 is probably most suitable for mapping applications. These benefits come at a price. The Yuneec H520 is more expensive than both the DJI Mavic and Phantom 4, but considerably cheaper than the Inspire. The ability to quickly interchange (‘hotswap’) different sensors is an advantage of Yuneec models.

Yuneec H520 drone. Image source: Drones Direct

DJI F550 Flame Wheel

The DJI F550 FlameWheel is a self-build multi-rotor hexacopter, designed with flexibility in mind. It provides a large stable platform, for aerial photography and videography. The basic frame can easily be modified to accommodate a variety of cameras, gimbals and equipment, and the six motors provide sufficient power to carry loads up to 300g. Flight time is up to twelve minutes, depending on payload. The Flamewheel will run on a variety of flight controllers including the Naza V2, DJI Wookong WK-M and Pixhawk. This platform can be fully customised/upgraded to suit the requirements of the user, and therefore is ideal for those pilots who want to use a wide range of equipment, without the need for multiple drones.

DJI FlameWheel drone. Image Source: DJI

Fixed wing

The biggest advantage of fixed wing drones is their ability to cover much wider areas on a single flight. Fixed wing drones get their lift from their wings, with the motor being used for thrust, as opposed to the multirotor which must constantly use its motors to resist gravity. For this reason the fixed wing can remain airborne for in the region of ten times longer on a single battery charge. This advantage comes at cost - fixed wing drones are considerably more expensive than comparably sized multicopters. Under low light conditions, fixed wing drones can produce lower quality images because they don't have the option to hover when the shutter speed is slowed.

A complete solution is offered by senseFly, for example their flagship eBee model with integrated eMotion mission planning software. The eBee is easy to launch - you simply throw it into the air. However, this is an expensive option. The eBee Classic weighs a mere 690g which is less than the DJI Mavic Pro. It can cover up to 140 ha in a single flight, and can fly in winds up to 28 mph.

Hybrid models

More recently, some hybrid systems have emerged which are designed to maximise the advantages of both multirotor and fixed wing systems. These new vertical take-off and landing (VTOL) units can be launched from a fixed position, climbing vertically and then switching to horizontal propelled flight in mid air. At the time of writing, the leaders in these new systems include the Aerovel Flexrotor and the Aerie Kestrel. These systems are assumed by the authors to be in a different price league to the previously discussed consumer grade drones, but affordable versions may enter the consumer market in the future.

Cameras and Sensors

The variety of cameras offered by different manufacturers in the drone world may seem overwhelming. New models are being launched every month, making selecting the right camera for mapping even more complicated. Thankfully the standard camera that comes with the better commercial drone offering such as those from DJI have improved dramatically and are suitable for most mapping purposes.

There are a number of critical features of a drone camera that need to be considered depending on the mapping outputs required. The built in camera in newer DJI models will be suitable for creating aerial imagery, and for basic vegetation classification (e.g. trees vs. herbaceous plants vs. bare ground). For detailed vegetation classification, or to generate the Normalised Difference Vegetation Index (NDVI), a camera with IR capabilities is required. These are considerably more expensive, and require moving from standard consumer drones and delving into the challenging world of customisation.

Many modern cameras come equipped with GPS capability as standard. This is preferable if using the images for photogrammetry (i.e. joining multiple images together into a composite image). Most cameras fitted to a modern drone will have GPS. The GoPro Hero 5 and later models are also equipped with GPS. Notes on how to acquire imagery with a camera that is not GPS enabled can be found in Ground Control Points.

Using fish-eye lenses for mapping work is not recommended. These are wide angle lenses, that create panoramic visual distortion. Some image processing software offer the option to specify camera models and lenses, and can correct for the distortion introduced by fish-eye lenses.

Cameras using a rolling shutter sensor are not recommended for mapping. These sensors do not capture the whole images at once - rather they scan across the image and capture it in sections. If the drone carrying the camera is in motion, this method introduces too much distortion for the images to be mosaicked together.

Drone camera. Image source: Max Pixel

Standard RGB Cameras

Standard RGB cameras work with the visible part of the electromagnetic spectrum. They detect the reflectance of red, green and blue light, in separate channels. These cameras are the standard on all off-the-shelf drones, and are well suited for aerial imagery.

Lens filters can be applied to standard RGB cameras to enhance their ability to detect certain features. Polarising filters suppress reflections on water surfaces, making it easier to identify underwater features, e.g. algae.

RGB cameras can be adapted for capture of infrared (IR) light. By default, they contain IR filters. It is possible to hack your camera to remove the IR filter, and apply a visible light filter, thus modifying your camera to detect IR light. A visible light filter could also be applied directly to your RGB camera, without removing the IR filter. This will allow the residual IR light to be detected. However, the amount of light measured will be small, and long exposure times will likely be required. More research is needed by CDMU to understand the reliability and limitations of these lens filters, but they could be a very cost effective approach for vegetation analysis.

Taking advantage of the different angles objects are captured at in multiple overlapping images, photogrammetry software can be used to create 3D surface models from images from RGB cameras (see Image Overlap).

Multispectral/Hyperspectral Sensors

Multispectral imaging involves the collection of data across the electromagnetic spectrum, usually including light that is visible and invisible to the human eye. Multispectral sensors capture the light reflected by vegetation and other objects, within broad and separate bands, e.g. near infrared (NIR) at approximately 760-900 nm. Given that not all objects absorb light in the same way, or absorb it differently under certain conditions, the amount of light they reflect, known as their spectral reflectance, also varies. Loosely defined, multispectral imaging involves three to six discrete bands. They typically include the broad bands of red, green and blue as well as a subset of red and blue bands, plus the red-edge and NIR. In contrast, hyperspectral imaging uses a sensor that captures information continuously between particular wavelengths. This signal is then captured in hundreds or thousands of discrete but adjacent bands.

Multispectral and hyperspectral images can be used to analyse vegetation health, type and change making them an increasingly vital conservation tool. The Normalised Difference Vegetation Index (NDVI), which measures the ratio between reflectance of red and NIR light, is a common example.

Recent advances in technology, in particular reduced weight of the sensor, has made drone multispectral and hyperspectral analysis possible. A current shortcoming in drone hyperspectral imaging technology is the computational resources required to mosaic the composite images together. Each reflectance band will generate a discrete image for each patch of ground. The more reflectance bands you use, the more computationally expensive it will be to stitch all the images together.

There are several leading options for multispectral cameras that can be mounted on a drone. Camera vendors will usually also sell mounts for popular drones, such as DJI drones. The budget option is the MAPIR Survey3, which collects light reflected in 3 channels (green, red and near infrared.) It can be mounted on a drone as small as the Mavic 2 Pro.

The Parrot SEQUOIA is probably the most widely-used drone-mounted multispectral camera. This camera is designed specifically to collect data on vegetation reflectance at different wavelengths, that can then be used to analyse vegetation 'health'. The compact and lightweight design of the camera allows it to be fitted to almost any drone. The Parrot SEQUOIA is more expensive than the MAPIR Survey3, but has some additional benefits. It collects one additional band of data (red edge), and is equipped with a down-welling light sensor, which is used to colour correct (standardise) images as they are taken, enabling for direct comparability between different flights and locations.

Some drone enthusiasts have hacked their drone's camera, and applied a filter so that one of the channels can record IR light. In addition to requiring technical skill, you also lose one of your RGB colour channels (see Standard RGB Cameras).

Electromagnetic spectrum, including visible and infrared light. Image source: Wikimedia.

For out-of-the-box drones, there is limited capacity to change the camera. For example, only DJI cameras can be easily used with DJI drones. To attach a non-DJI camera to a DJI drone, you usually also need to replace the gimbal, which holds the camera. Kits are available for mounting non-native cameras on drones, for example, for attaching the Parrot Sequoia multispectral camera onto DJI drones. The greatest flexibility in changing your camera comes from building the drone yourself.

LiDAR

Light detection and ranging (LiDAR) is a surveying method that targets the object of interest with a pulse of light, and measures the time taken for the light to reflect back to the detector. The time taken corresponds directly with the distance to the object, allowing the position of the object to be accurately determined. It is commonly used by manned aerial flights for measuring elevation, and the height and texture of surface structures, such as buildings and vegetation.

LiDAR digital terrain model (DTM) with hillshade. Image source: CDMU.

The application of drones as a flexible sensor platform for monitoring has evolved rapidly. In the past, LiDAR measurements were made only from manned helicopters or airplanes. LiDAR sensors were too heavy to mount on a drone. Nowadays, larger drones can carry a LiDAR sensor. Potential application domains include agriculture (phenotyping of individual plants), coastal monitoring, dikes, archaeology, corridor mapping (power lines, railway tracks, pipeline inspection), topography, geomorphology, construction site monitoring (surveying urban environments), forestry, vegetation monitoring, and peatland restoration. Currently LiDAR sensors are very expensive and their use at the RSPB is likely to require a third party company rather than in house users.

Thermal Sensors

Thermal sensors detect heat, by measuring infrared radiation emitted by objects. A much wider range of IR wavelengths are used for detecting heat, than when using IR for vegetation monitoring. The Zenmuse XT is a thermal integrated camera, developed by FLIR for DJI drones. Due to the weight of thermal cameras, they need to be carried by larger drones, such as the Inspire or the Matrice. A Zenmuse XT2 camera with a Matrice 200v2 drone is being used by RSPB to detect goats at Inversnaid.

The resolution of thermal cameras is much less detailed than standard RGB cameras. Care needs to be taken to select a camera that can record an adequate resolution for your purpose. A resolution of 640 x 512 pixels is suitable for detecting nightjar nests. A lower resolution can be used to monitor larger animals, for example herbivores. Limitations exist if there are places for the animals to hide (e.g. under tree canopy), and that they may be easily scared by the drone. False positives can also be a problem, particularly when monitoring birds.

To get the best thermal contrast between your target species and the surrounding background environment, thermal images should be collected at dawn, before the day has warmed the ground up.

Batteries

Unlike military grade surveillance drones which run on solar power, commercial drones run on battery-supplied electricity. Battery life is a key factor in drone flight planning. Battery life and weight are improving all the time, but these are still the main limitations for flight times. Batteries can also be expensive, and are a key factor to consider when purchasing a drone. Just a single battery can cost 10% of the drone unit cost. The number of spare batteries you need will depend upon your intended use, but for most mapping surveys it is recommended to have at least four, which equates to approximately one hours flight time. Most drone flying software will automatically fly the drone ‘home’ when power is low, but always be vigilant. Remember that power failure could be disastrous for both your drone and any people in the nearby area. It is recommended to operate a rule of thirds i.e. your flight should be half complete when the battery is at ⅔, and you should be aiming to land with ⅓ battery remaining.

Most commercial drones now use lithium-ion polymer (Li-Po) batteries. There is a wealth of information around battery care for Li-Po batteries, but the two key issues are storage and optimal temperature. The batteries should be at room temperature to function correctly. A common trick in the field is to place the battery under your armpit to warm it up! Storage energy levels, i.e. the amount of energy stored while the battery is not in use, are also important to prolong battery lifetime. The optimum storage level will depend on the battery model but the norm is 40%. It is very important to not let batteries run down to empty during storage as this can lead to the battery becoming permanently ‘dead’. There is a higher risk of fire from Li-Po batteries than other batteries. Care should be taken, particularly when charging the batteries. Only use a charger specifically designed for charging Lithium Polymer cells, and do not recharge a battery if it is damaged or swollen. It is advisable to charge and store Li-Po batteries in Li-Po fire safety bags. Damaged batteries should be carefully discarded at appropriate locations.

See the link below for more info on battery care and operation:
http://www.dronethusiast.com/ultimate-drone-battery-care/

Also see this link on fire risk of Li-Po batteries:
http://batteryuniversity.com/index.php/learn/article/safety_concerns_with_li_ion

Mobile devices

You’ll most likely operate your drone using an app on a tablet. It is possible to use a smartphone, but this is not recommended, due to the small screen size. Your drone’s user manual will contain instructions for pairing the drone with your smart device. For complete functionality the device should have GPS capability. Access to 4G will make your system much easier to use.

Using your smart device, you can either pilot your drone manually, or use mission planning software to programme your drone. Even when using a programmed flight, many drone pilots prefer to switch to manual flight for take-off and landing. Your smart device is also vital for monitoring diagnostics during the flight, such as the amount of battery remaining.

Tablets can overheat when flying drones for prolonged periods, or in hot weather (>30^{0}C). Reflections and glare from the tablet screen can be a problem on bright days. Glare can be reduced with a sun shade or an anti-glare screen protector. Reducing glare will also allow you to turn down the screen brightness, which will help the tablet battery last for longer.

Software

Flight Control

All drones come with a remote control system, that allows you to control your flight. There are several options for augmenting the drone flying experience with mobile apps downloaded to a smartphone or tablet. Apps can unlock advanced features above and beyond the buttons on the factory supplied remote control device, such as a live video link enabling the pilot to see from the drone's point of view.

For DJI drones, the DJI GO app can be downloaded from the Google Play store for Android devices, or from the Apple App Store for Apple devices. The DJI GO 4 app is optimised for all of DJI's products since the Phantom 4, including the Inspire 2 and the Mavic Pro. However, the app has so far received considerable negative feedback, mostly pertaining to a tendency for the app to crash or otherwise disconnect from the drone. Others have cited forced firmware updates which render the drone incompatible with certain mobile devices. However, this is a rapidly evolving field, so it's worth reading reviews for the reliability of the current version.

Mission Planning

While drones can be flown manually, when they are used to collect data for GIS it is advisable to use mission planning software. This allows the user to define an area of interest on the map, and set the overlap between images (see Image Overlap). The mission planner will then calculate the most efficient flight path and send the route to the drone. The mission planning software will adjust the speed of the flight to account for light levels and shutter speed, minimising image blur. A further option offered by some mission planning programs (e.g. DJI GS Pro) is 'hover and capture at a point'. Using this option will cause the drone to pause flight and hover each time an image is captured. This ensures that the camera is stable every time it captures an image, and there will be no image shear or motion blur. This setting may be particularly useful in low light levels where longer exposure times are needed to capture quality images, but bear in mind that the flight time will be greatly increased when using this option.

DJI pilots have access to a free dedicated app called DJI GS Pro (Ground Station Pro), which unfortunately is currently only available on the newest Apple devices. GS Pro is designed to plan and control automated flights for DJI drones. A drawback is that currently this mission planner will only support a maximum of 99 waypoints. However, a real advantage available in several mission planning apps, including GS Pro, is the ability to complete a mission in several flights. Once the battery reaches a critical threshold (usually set by default to ca. 30%), the drone will return to home on autopilot (note, there is always the option to override the autopilot). The battery can then be replaced and the mission resumed; the drone flying back to where it left off to resume the mission. The pilot must remain vigilant when the flight is resumed, as occasionally the flight may not continue as expected. The GS Pro app supports KML, SHP, KMZ and ZIP polygon formats. Currently, WGS 84 is the only coordinate system supported by DJI GS Pro. For further information see the DJI GS Pro User Manual.

Another iOS option is Map Pilot by Drones Made Easy, available on the Apple App store for £9.99. Imagery can be uploaded from the app directly to Maps Made Easy, turning this into a full drone-to-map solution. However, this option is expensive, if you have multiple flights. Note that Map Pilot can underestimate flight times, particularly if there is some wind, and under low light conditions. Map Pilot can also complete a single mission in multiple flights, after the battery is changed. Pix4D also offers free mission planning app, called Pix4Dcapture, which is available for both IOS and Android. Be aware that Map Pilot cannot be used with Mavic 2+ drones, due to their inbuilt screens.

A further advantage of using a mission planner is that you can save your flight plan, and re-use when you need to resurvey the area. This ensures that the images are collected in the same locations.

Mission Planner ground station software. Image source:
http://ardupilot.org/planner/docs/mission-planner-overview.html

Yuneec drone pilots can download the DataPilot app for free. It is currently only available for Android and as a desktop application. For drones using the Pixhawk & ArduPilot autopilot hardware/software combination, the popular solution for mission planning is Mission Planner. Mission Planner is a free, open source ground station application but is for Windows only. As the name suggests, Mission Planner can be used to design flight paths for your drone. It can also monitor the status of your drone in real time and can be used to operate the drone in first person view (FPV).

While most mission planning firmware is fairly straight-forward to use, the instructions provided are sometimes not very clear. There are lots of useful tutorial videos on YouTube. If you're going to be working remotely in the field, it's worth taking the instruction manual and any other helpful documentation into the field with you, in paper or digital format.

Firmware Updates

You will need to be cautious with updates to your drone, and any associated firmware on your smart device. Smart devices often have settings allowing automatic installation of updates, whereas your drone will probably not receive automatic updates. This can result in incompatibility between versions, meaning you will not be able to fly your drone until all the updates are made. Frequent drone fliers often disable automatic updates for their drone firmware. If you do disable your automatic updates, remember to manually update your drone and smart device firmware regularly. Ensure that the latest stable firmware is installed before each flight.

Image Processing

Data Requirements

For the images captured by drones to be suitable for use in GIS, geographical information needs to be recorded for each image. The minimum data required for image processing software to work are latitude, longitude and altitude. The latitude and longitude are recorded by the drone's GPS device. Altitude can be recorded by GPS but this can be inaccurate. Most mid range and up drones will record altitude using a barometric sensor which is more accurate, but note that readings can shift with rapid changes in weather conditions. The information is either written directly to the image metadata (stored using the EXIF data standard) which can be viewed by accessing the image properties window in Windows Explorer, or the data are written to a timestamped log file that links the images with the geolocation information. Most software can process images in both of these formats.

Image metadata showing EXIF data, accessed using Windows Explorer. Image Source: CDMU

Processing outputs

With a standard small digital camera, drones can provide a variety of data (see Standard RGB Cameras). This includes raw aerial imagery, natively stitched mosaics (photomaps), orthorectified mosaics, point clouds, and digital surface models (DSMs). There are a host of software applications on the market that can process raw drone imagery into these products. Some of the most established applications include Pix4D, ESRI's Drone2Map (which uses the Pix4D engine), Photoscan and ENVI OneButton. These applications are fairly costly and one license can range from a few hundred to thousands of pounds. The licensing costs are continually coming down, and there are cheaper options such as ESRI's ArcGIS Pro which despite not being a dedicated image processing application has an orthomapping module. There are also free open source options such as OpenDroneMap, as well as software as service options such as PrecisionMapper where images can be uploaded to the cloud and processed for a fee. These computer programs are often referred to as computer vision-based, however the algorithms they use to develop their high-accuracy products are based on photogrammetric models. Although the workflow and theory behind the software suites are very similar, each has moderate algorithmic variations which may result in slightly different results.

Processing times can be long, and depend on computational power. Reducing the resolution for shorter processing times is advisable if high resolution imagery is not essential. The resolution of the output image can be set when you run the software. If a high precision output is required, CDMU can run the analysis on a high spec computer.

Currently RSPB is using ESRI's Drone2Map for image processing. Drone2Map requires latitude, longitude, and altitude data for each image processed. For 2D mapping at least 80% frontal and at least 70% lateral image overlap is normally required, and the images should be taken pointing directly downwards. For homogeneous vegetation, lacking manmade features with strong geometric edges, maximising overlap (perhaps to 90% in line) will produce better results. Drone2Map can also create point clouds and digital surface models (DSMs) for 3D landscape modelling. As an example of the time taken to process images in Drone2Map, a 50ha area at Abernethy, comprised of 130 individual images, took 41 minutes to mosaic into a single georeferenced image, on a high spec PC with a 3.4GHz processor and 64GB RAM. However, the amount of time required to mosaic images increases non-linearly with additional images. Creating a composite from 450 images took over 7 hours on the same PC.

Drone2Map. Image Source: ESRI

The Drone2Map application is intuitive to run with the default settings, and CDMU encourages those involved in drone mapping work to use the application themselves. However, CDMU does provide an image processing service. It should be noted that Drone2Map requires a 64-bit computer with at least 8GB of RAM. CDMU will provide training and support for Drone2Map users. Contact CDMU if you'd like to take advantage of this service, or if you're interested in processing your own images.

The processed outputs can be added to GIS applications including Merlin and ArcGIS for display, overlay with other mapping layers, and analysis. CDMU can advise on how to do this. Publication of data to Merlin is carried out by CDMU. To ensure that appropriate quality data are collected, it is recommended that CDMU are contacted prior to flying, if you want data published to Merlin, or used in GIS.

Note that conventional image processing software, such as Photoshop, can be used to mosaic images together, but the geographic information is lost. The outputs are not easy to use in GIS.

Operational Advice

It is strongly advised to follow a pre-flight checklist and complete a flight log for every flight. An example is provided in Appendix II. Temporary signage should be devised and erected in the vicinity during operations to inform the public that permitted drone surveying is taking place. This reassures the public and conveys a sense of professionalism to the operation. Commercial licences and CAA permissions are required when using drones commercially for paid work or specifically capturing imagery to promote a site or attract visitors.

There is a potential liability for flying a drone without the latest firmware - this must be checked as a matter of urgency before each flight. Pre-flight checks and calibration in accordance with the specific drone used to be carried out.

Safety

As detailed in the Code of Practice, and the CAA guidance, drones should not be flown at an elevation greater than 120m, or within 50m of people and structures that are outside the control of the operator. The operator must maintain line of sight with the drone at all times.

It is advisable for drone pilots to have a competent assistant who can act as a spotter, and help respond to any issues arising. If using First Person View (FPV) technology, someone must also keep a visual fix on the drone at all times. Where an emergency return to home (RTH) function is available, it must be activated before the flight, and set to a suitable height.

The pre-flight checklist should always be completed for safety and to ensure a smooth flight (see Appendix II: Pre-flight checklist and flight log).

Environmental Conditions

The biggest environmental concern to a drone operator is wind. Your drone will have a published wind resistance limit. As a general guide, it's best not to fly in winds over 20mph (or at or above Force 5 "Fresh Breeze" on Beaufort scale). Bear in mind that wind speed increases with height. If it is windy, try to find a sheltered position to take off and land, as small gusts at ground level can flip the drone, which can damage the propellers. Gusts can also cause problems in-flight, making the drone more difficult to control. If you have mobile reception where you are flying, there are useful, free wind forecasting apps such as Windyty and UAV Forecast.

It's not advisable to fly in the fog or rain. Fog limits visibility, so you won't be able to fly very far and keep your drone in sight. Many drones are not waterproof, so if there's a risk of rain, the mission should be aborted.

Sunny days, and bright overcast days, can cause glare on the mobile device used to control the drone, and make the screen difficult to see. A sun shade or an anti-glare screen protector may help. Bright, overcast days often result in good images, as shadows are minimised. On sunny days, flying at midday will reduce the impact of shadows. Under low light conditions, the images collected will be darker, and the flight will take longer as exposure times will need to be longer

Collision Risk

Before starting a flight, check for hazards, including overhead wires, trees, people, and water. Choose a launch site that is open, flat, and as far from trees, other tall vegetation and water as possible. This provides a safer return to home (RTH) location, as in some drones the RTH functionality brings the drone directly home, in a straight line, which may result in a collision with nearby obstacles. Newer drones, including the DJI Mavic and the Phantom 4, have integral collision avoidance mechanisms to avoid collisions. These should be activated if available, but pilots should take into account terrain and obstacles around to avoid near-miss collisions. However, this is not a substitute for vigilance of collision risks.

Another potential collision issue concerns flying over steep terrain. Drone piloting firmware will aim to fly your drone at a constant height, determined by its starting altitude. You may crash, if the ground elevation or the height of objects increases by more than your drone's altitude. Map Pilot offer a terrain following in-app purchase, which may be useful in certain environments.

There is a useful new mobile app called Drone Assist by NATS which is available on IOS and Android. It presents users with an interactive map of airspace used by commercial air traffic so that you can see areas to avoid or in which extreme caution should be exercised, as well as ground hazards that may pose safety, security or privacy risks when you're out flying your drone.

Source: Google Play

Wildlife disturbance

Keep an eye on birds for potential disturbance at all times. Any intentional flying near a schedule 1 species needs to be licensed for disturbance. Beyond that, the advice given here is a set of guidelines only; individual species can vary tremendously. Even flying at 120m can spook a flock of geese, while 7m from a cliff edge has produced no reaction. Birds are often more disturbed by a horizontal approach than a vertical approach, even at a height of 60m. A vertical approach causes considerably less disturbance. Never hover lower than 12m (40ft) over nesting birds. Higher may be completely adequate. Mammals can also be easily frightened by a drone hovering at 120m.

Papers addressing the impact of drones on wildlife are beginning to be published. For recent examples, see:

- Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review. (Mulero-Pázmány et al.,PLoS ONE 12(6), 2017)
- Approaching birds with drones: first experiments and ethical guidelines (Vas *et al.*, 2015)
- Evaluation of unmanned aerial vehicle shape, flight path and camera type for waterfowl surveys: disturbance effects and species recognition (McEvoy *et al.*, 2016)

Best Practice for Mapping

Image Overlap

The amount of image overlap specified as a percentage is vital for image processing such as orthomosaicing (image stitching) and digital surface models. These types of processing use the science of stereophotogrammetry, also known as Structure From Motion (SFM). Stereophotogrammetry uses multiple photographic images taken from slightly different positions to estimate the three-dimensional coordinates of points on an object. The basic principle of stereophotogrammetry requires the matching of features between images to form a single contiguous model. The images need to overlap considerably in order for features to be matched across several images. For 2D products the images should be collected in a regular grid pattern. The recommended overlap for most cases is at least 80% frontal overlap (with respect to the flight direction) and at least 70% side overlap (between flying tracks).

Poor image overlap is one of the biggest culprits in making drone imagery unsuitable for GIS. The flight control app you use should allow you to specify image overlap, both frontal and side. Image processing software, such as Drone2Map, will produce a report showing which areas of your project had poor overlap. Although, ideally, proper use of the mission planning software should negate these problems. Be aware of changes in terrain and use a suitable altitude for starting your mission. If you start on low ground in a hilly area, the drone will fly closer to the ground at the hill tops. This reduces the altitude over the higher areas, which will result in poor and variable overlap of your images. Recommendations for image overlap depending on the terrain type can be found in the Terrain Types section.

Schematic showing drone flight path over an area of interest. Image source: http://www.mining.com/web/how-a-sensor-gimbal-improves-efficiency-of-an-aerial-mapping-mission/

Another factor to consider is movement between overlapping images. Any movement between images can cause the stitching to either fail or to produce a blurry or distorted image both in the digital surface model, as well as the orthomosaic aerial image. Typical examples of where this may occur are water surfaces e.g. ripples and waves on a pond and vegetation moving in the wind. The photogrammetry software will struggle trying to match these images and will tend to produce imperfect results. It is therefore recommended to fly in still conditions when such features are going to be in shot.

Animated illustration of moving reedbed affecting colours and light levels between two images. Image source: Colin Casey

Image Obliqueness

Obliqueness refers to the angle at which the images were taken. For 2D mapping it is essential that there is minimal image obliqueness i.e. the images should be taken pointing straight down, with zero pitch. This is referred to as 'nadir' imagery. While some obliqueness can occur in flight and this can be handled by most orthomosaicing software, it should be minimised.

For 3D models and inspection flights, collecting images at oblique angles is required to get the optimum detail. In this case nadir imagery is obtained, in addition to oblique imagery. The image below shows the improvement to a 3D model with the addition of oblique imagery. This can be be achieved by flying multiple passes e.g one flight with nadir imagery (to collect information about the horizontal surface) and then further flight taking oblique imagery with the camera at angle (for the vertical surface). For 3D images of structures, a helter skelter flight path can be used. See section on Vertical Mapping below for more information.

3D models are improved by including oblique images. Image Source: www.dronedeploy.com

Terrain Types

For homogeneous terrains, better images can be obtained by modifying the standard overlap guidance given in the Image Overlap section. For forest mapping, it is recommended to increase the overlap to at least 85% frontal overlap (with respect to the flight direction) and at least 70% side overlap (between flying tracks). The altitude should also be increased to minimise perspective distortion. The maximum permitted flight height is 120m in the UK.

For flat, homogenous landscapes, such as agricultural fields, it is best to increase the frontal overlap to at least 85%, the side overlap to at least 70%, and to increase the flight height. When mapping linear features, such as rivers, fly a minimum of 2 tracks along the feature using at least 85% frontal overlap and at least 60% side overlap. For transects, or other less identifiable linear features, more tracks are recommended.

Shadows can decrease the quality of images of heterogeneous habitats. To minimise the impact of shadows, either fly on an overcast day, or when the sun is high in the sky.

If your flight area involves a significant elevation change, ensure that you are flying your drone high enough. The drone piloting firmware will usually aim to fly your drone at a constant height, determined by its altitude at your starting point. If you start your flight over low ground, and the ground elevation or the height of vertical objects increases by more than your drone's altitude, you run the risk of crashing. Additionally, if the effective altitude decreases, because the ground becomes closer to your drone, the overlap in your images will increase. Be sure to start your flight at a sensible elevation relative to the terrain change over your flight path. Starting at an intermediate elevation will help minimise the variation in image overlap, in addition to reducing collision risk.

When flying over water, stay away from larger structures that may interfere with the signal between your smart device and your drone. Wind can be higher over water, and since flying in higher wind uses more energy, you need to be particularly cautious to return your drone with enough battery remaining. When taking off from a boat, it is advisable to hold your drone when you launch, to ensure it clears the body of the boat. When landing into a boat, you must land the drone manually, as the boat will almost certainly have moved from the position you started, meaning you cannot necessarily rely on the automatic return to home. Some mission planning apps (including DJI Go) have a dynamic home point feature, which will return the drone to the controller, rather than the point it took off.

GPS/Positional Accuracy

Most drones have a built-in GPS, IMU (Inertial Measurement Unit) and barometric altimeter, to aid with navigation. The default positional accuracy is generally good enough for many GIS applications. For example the DJI Phantom 3 Pro has a positional accuracy of ±1m. The accuracy tends to decrease once the images are mosaicked together, typically to about ±5m. If necessary, you can improve the positional accuracy by using ground control points (GCPs), see Ground Control Points.

When using drone imagery for GIS, you need to ensure that you have a way of recording the location where each image was taken. The easiest way to do this is to use a GPS enabled camera, that records the latitude, longitude and altitude in the image file properties. If your camera does not tag the photos with location information, you will need to record the location of the images separately. This can be done by creating a flight log, for example, using mission planning software. Most software used to mosaic individual images into a composite image can still automatically process images that are not georeferenced, as long there is a flight log file.

Images with no positional information, including no flight log, can be mapped in a desktop GIS, such as ArcGIS. However, this involves a laborious, manual georeferencing process, in which points on the image are visually matched with a reference basemap.

Ground Control Points (GCPs)

Ground control points (GCPs) are used in image processing to improve the positional accuracy of data. GCPs are physically marked locations with a fixed position, whose coordinates have been precisely determined (e.g. by using a combination of navigation systems such as GPS and GLONASS, or by using differential GPS). It's advisable to use at least 4 GCPs, evenly distributed throughout the target area. The GIS output is physically aligned with the GCPs in 3 dimensions, increasing both global and local accuracy. Check points should be taken along with GCPs. These are not used to adjust the project, but are used as an independent accuracy check. In short, GCPs are essential to provide project accuracy, and check points are used for verifying that the position of your data is correct. The most common method for recording GCPs is via a real-time kinematic (RTK) enabled GPS receiver using correction data streamed from a nearby reference station. Equipment with this degree of positional accuracy is expensive, and probably not necessary for most RSPB applications. Similarly, some drones are now equipped with RTK, which negates the requirement for GCPs.

Most image processing software, such as ESRI's Drone2Map, allow the user to enter GCP information to improve the accuracy of their results.

GCPs may be beneficial in the following situations:

1) Your drone has no GPS capability
2) Your drone GPS has low accuracy
3) You require >5m precision for your mapping outputs
4) You are creating a digital surface model and need accurate absolute elevation values

For more information on the use of GCPs and how to set them up see the following blog post: https://blog.propelleraero.com/things-to-know-about-ground-control-in-drone-surveying-6b63ba6ccf0c.

This blog assesses the optimal number of GCPs in a drone study area: https://www.pix4d.com/blog/GCP-accuracy-drone-maps

Elevation Mapping

Mosaicking drone images together using photogrammetry creates a Digital Surface Model (DSM). When flying a mission with the intention of collecting elevation data, ideally Ground Control Points (GCPs) should be used to increase the positional accuracy of the measurements. GCPs are less important for applications that only require relative measurements, for example identifying drainage networks. CDMU are still working to identify the best flight parameters for collecting DSM data. Our investigations so far, suggest that DSM errors are greatest on steeper slopes, and at the edges of survey areas. To minimise these errors, and increase the reliability of your DSM, increase the image overlap if the terrain is hilly, and include a buffer around your area of interest. On flatter ground, it may be adequate to include a 25m buffer around your survey area. If there are hills towards the edges of your survey area, a larger buffer would be advisable.

Vertical Mapping

Successful botanical surveys of vertical cliffs have been conducted using drones. The following recommendations come from an unpublished report by Ben Nyberg at the National Tropical Botanical Garden in Hawaii, who has extensive experience surveying plants on steep cliffs. Typically, the drone was flown in a series of horizontal sweeps, 7m from the cliff. The camera angle was set at 20° from the nadir (looking straight down), and images were taken with 50% frontal and lateral overlap. In these surveys, this meant the altitude of the drone was increased by 4m with each successive sweep, until the survey area was covered. This approach gave pixels with a width of several mm. A live feed video from the drone can assist with the flight. Extreme care must be taken to avoid collisions with vertical terrain. Most modern drones (e.g. Mavic series and Phantom 4 onwards) have collision avoidance sensors. These provide the pilot with the distance to the surface. Keeping a constant distance from the surface is important for maintaining a consistent resolution.

Light levels

It's generally best to minimise the presence of shadows, and changes in light levels while imagery is being captured. Differences in light levels between images can make it more difficult for the photo stitching software to match the images, and create a composite mosaic. Even if the images can be successfully mosaicked, shadows and inconsistent light levels can cause further problems if you want to perform an image classification (e.g. habitat classification) on your product. If you plan to do a time series analysis (i.e. compare images captured on different dates) then it is also best to try and minimise differences in light between flights. Tips for making your images more comparable include flying at the same time of day, and under similar cloud conditions. If you are looking at annual changes, fly at the same time of year. Overcast days can be useful because they create 'flat' light which illuminates all surfaces evenly and doesn't create shadows.

It is possible to use an irradiance sensor which sits on top of the drone and measures the intensity of incoming radiation. The images are then corrected for varying light levels during the flight. The caveat is that the irradiance sensor only measures light intensity at a point location (the drone) which may be experiencing different light levels to the rest of the area in the image, particularly if experiencing sunny intervals. In any case, most drone solutions currently do not employ irradiance sensors and so vigilance to light level fluctuations and shadows is needed from the pilot.

Irradiance sensor Image source: https://pix4d.com/sequoia-faq/

Ground Sample Distance (GSD)

The ground sample distance (GSD) is the real-world size of a pixel in your images which generally sets a physical limit on the detail of your aerial survey. The GSD is measured in cm/pixel. For drone imagery, the GSD is typically 5 cm/pixel, or better. If your GSD is 5cm, you will be unable to see details smaller 5cm in size. The GSD is influenced by:

- The distance between the camera and the object
- The size of camera sensor
- The camera resolution
- The focal length of the camera lens
- The camera lens aperture

A higher resolution camera will improve the GSD which means you can fly higher and achieve the same quality results, thus reducing flight time.

The variables mentioned above are discussed in more detail on the blog post below:
https://blog.propelleraero.com/what-makes-a-good-camera-for-drone-surveys-and-inspections-460fb9fb7099

Some mission planning apps, including Map Pilot, display the GSD on the standard flight information screen. Alternatively, Pix4D have created a GSD Calculator which can be used in Excel. This lets you change the flight and sensor parameters and view the resulting effect on GSD. This is an easy way to calculate the altitude you need to fly at to achieve your desired GSD. The Excel workbook is available at:
https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-Calculator#gsc.tab=0.

Pix4D ground sampling distance calculator. Source: Pix4D (https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-Calculator#gsc.tab=0)

Resolution

The ground sample distance (GSD) determines the pixel size, which is key to determining the final image resolution. Since file size is determined by the number of pixels, the more detailed your image, the larger the file will be. As a general guideline, halving your pixel size will quadruple your file size. You will be unable to clearly identify objects smaller than a single pixel. However, it is often possible to infer an object whose size is at least half a pixel. The resolution required for a particular project will be dependent on size of the target objects, and the detail required.

The resolution of your images will be dependent on the height at which the drone is flown, and the size of the sensor in your camera. A lower flight produces smaller pixels, and hence a more detailed image. As a rough guide, the DJI Phantom 3 Pro produces ca. 5cm pixels, when flown at 120m. Dropping to an altitude of 50m reduces the pixel size to ca. 2cm.

Comparing the detail captured at different pixel resolutions. Image source: CDMU.

Applications

Vegetation Analysis

Tips for surveying vegetation

When mapping vegetation, consider whether the target habitats are more easily identifiable at a particular time of year. For example, bracken is most obvious when it has died back in the winter, while heather is most striking when it is in flower. Conifers are most easily distinguished from deciduous trees in winter. A light dusting of snow makes more textured vegetation, such as small trees and scrub, stand out more clearly. Consider when your target species is most conspicuous.

Shadows can help or hinder vegetation analysis. Shadows can accentuate vegetation structure, but they can also obscure shorter, adjacent vegetation. To accentuate shadows, fly when the sun is lower in the sky. To minimise shadows, fly in the middle of the day, or on an overcast day.

For monitoring change, repeat images of the same location will be necessary. For most vegetation change analysis, annual images are sufficient. If you are comparing vegetation year on year, the comparison will be clearest if the images are collected at the same time of year. For more comparable images, try to ensure that the light conditions are as similar as possible, e.g. taken at the same time of day.

Vegetation indices

There are indices available for assessing vegetation health, which can also be helpful in distinguishing different vegetation types. The normalised difference vegetation index (NDVI) is a widely used index that compares reflectance in the red and infrared bands. This requires that your camera can detect infrared light. NDVI varies between -1 and 1, with a higher value indicating lusher, greener vegetation.

An alternative index that can be derived using a standard RGB camera is the Visible Atmospherically Resistant Index (VARI). This can be viewed as a measure of "greenness." While VARI has the advantage that it doesn't require a special camera, it does tend to be used for drier habitats. The reliability of VARI for vegetation monitoring in the UK needs to be investigated further.

Vegetation classification

Classification is another way of analysing vegetation data. It refers to grouping areas into categories and assigning a habitat class, e.g. water, bare ground, grassland, scrub, coniferous trees, etc. This is a time consuming process, but using classified data it is much easier to measure areas, and quantify change. Aerial images can be classified by manually digitising habitats in GIS software, such as Merlin.

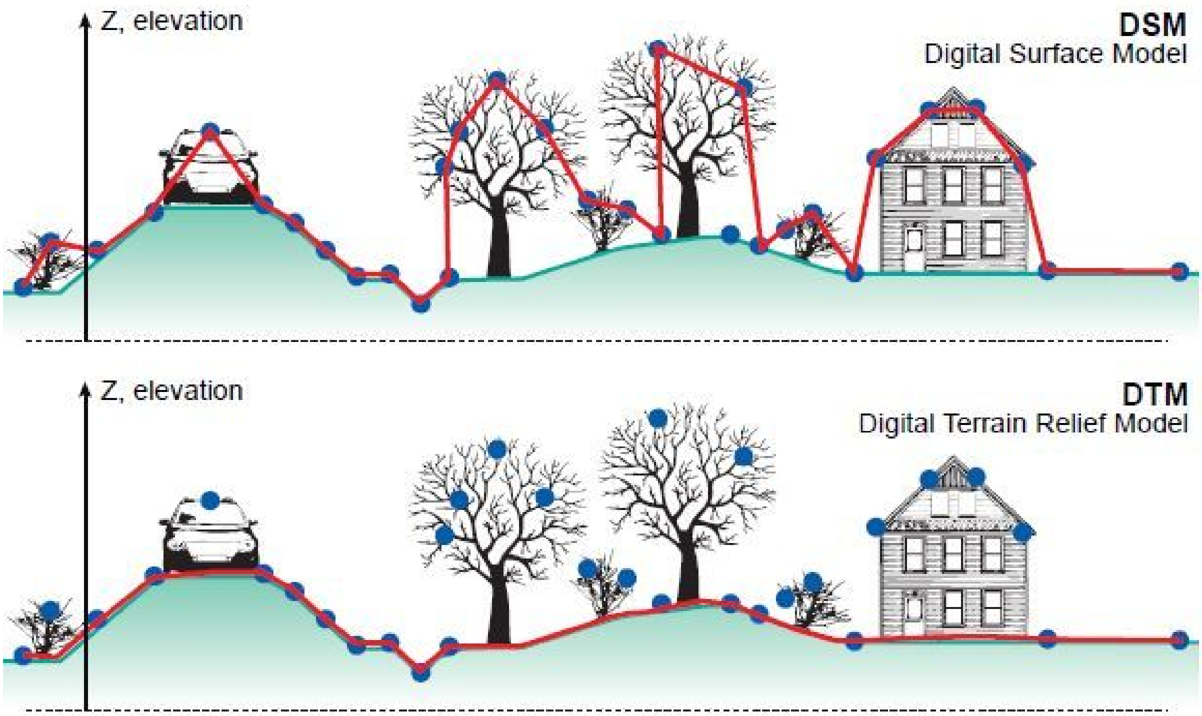
Alternatively, data can be classified semi-automatically, using specialised GIS software. Since drone imagery tends to have very high spatial resolution, there can be a substantial variation in pixel colour for each vegetation type. For this reason, it is advisable to automatically group similar pixels (i.e. pixels that are likely the same land cover) before classification, in a process called "segmentation." In an initial unsupervised classification of peatland from a multispectral drone image, bare peat was classified with 83% accuracy. This could almost certainly be improved by using a supervised classification, but the process will be considerably more labour intensive. CDMU can provide advice to advanced GIS users who would like to attempt an automated classification.

CDMU can provide classification of drone imagery as a service. Contact CDMU before your field visit if you'd like to use this service as additional training and verification data need to be collected on-site.

Note that land under shadow is particularly difficult to classify. Efforts should be taken to minimise shadows, such as flying at midday, or flying while overcast.

3D Analysis

The process of using stereophotogrammetry to mosaic images together also creates a 3D point cloud, and a Digital Surface Model (DSM). The DSM shows the elevation of the 'tops' of the objects photographed, at the same resolution as the aerial image. Where vegetation is absent, the values in the DSM will be equivalent to the ground elevation and you will effectively have a digital terrain model (DTM). Otherwise the DSM value will reflect the surfaces of objects, such as vegetation and buildings. The absolute elevation of points can be inaccurate when derived using photogrammetry, particularly if not using Ground Control Points, but the relative elevation within a flight should be fairly reliable.



Comparison of DSM and DTM. Image source: http://www.charim.net/datamanagement/32

When you have created your DSM, there are immediately a suite of other data that you can readily derive using GIS. These include slope (degrees or percent), aspect and hillshade, which themselves can be used to calculate flow directions and watersheds. This opens up the possibility for hydrological modelling, e.g. mapping drainage patterns. You might want to identify south facing slopes that would be suitable locations for basking reptiles, or steep slopes which would be inaccessible to grazing stock. If you are interested in the ground elevation than the elevation of the vegetation canopy, it is advisable to fly when the vegetation has died back, i.e. during ‘leaf-off’ conditions.

Elevation profiles generated from DSM. Image source: CDMU

The main shortfall using photogrammetry to produce a DSM, as compared to using LiDAR, is that it isn't (generally) possible to produce a bare-earth DTM. It is therefore difficult to calculate vegetation height, which relies on subtracting the DTM from the DSM. However, if you have access to a one-off LiDAR survey that produced a DTM then, assuming that the terrain didn't change height (e.g. earthworks or major erosion), you could use this same DTM repeatedly, while using a drone to create regular up-to-date DSMs from which you could calculate vegetation height. To do this, your drone data will need to be accurately calibrated, both vertically and horizontally. It is advisable to use Ground Control Points (GCPs). Otherwise the drone data will likely need additional georeferencing. The vertical measurement in your area of interest can be corrected using the LiDAR DTM. This can be easily done, if your drone DSM covers areas of ground with minimal vegetation. The UK statutory agencies are increasingly making LiDAR data openly available. Contact CDMU for more details on what is available in your area.

Note that some drone mosaicking software can now create an interpolated DTM. This method is designed for urban settings, and is unreliable for modeling the surface elevation under vegetation.

Another potential use of a DSM is to assess vegetation structure. This can be done by using a 'moving window' analysis to measure the relative variation in the surface of the vegetation. For example, the Focal Statistics tool in ArcGIS can be used to calculate the standard deviation or range of values in a 7x7 moving window. A larger value is indicative of a more textured surface, heterogeneous surface, such as trees or scrub. Lower values would be expected for more even surfaces. Note that sloped surfaces can also produce a large range of values, so this technique is only applicable to fairly flat or consistent surfaces.

Focal statistics moving window analysis. Image source: pro.arcgis.com

To derive additional structural information beyond that provided by the DSM, you could analyse the point cloud directly e.g. using LAStools. These tools are typically used with LiDAR data but are currently being developed for use with photogrammetry data.

Hydrological Modelling

In areas with short vegetation or exposed ground, the Digital Surface Model (DSM) can be used as a surrogate for the ground elevation. This method has been used to delineate watersheds and to create a drainage network for imagery of degraded peatland. The output will necessarily not capture every ditch, as some may be obscured by vegetation. But it can still form a useful tool for planning where dams should be placed for peatland restoration. Hydrological modelling requires advanced use of GIS, but CDMU can advise qualified users on a suitable workflow. Alternatively, CDMU can run the models for you.

Drainage network created from drone imagery. Image source: CDMU

Mapping Nest Sites

Using a drone provides a means of mapping bird nest sites in inaccessible areas, and areas where physical surveys cause excessive disturbance. It is a reproducible technique that can be used for repeat visits. Drone nest survey mapping can be particularly beneficial for seabird cliff colony counts, and finding nests in reedbeds. A key element to consider when planning to map nest sites is the resolution required. A DJI Phantom 3 Pro flown at 120m has a pixel size of ca. 5cm, and of ca. 2cm when flown at 50m. The pixel size will need to be small enough to capture the detail required to identify and count the nests.

When using a drone to monitor nest sites, it is important to ensure that the count methodology is consistent with established methods, particularly for long term monitoring studies. If multiple photographs are required to cover the whole site, care needs to be taken to avoid double counting. Individuals may have moved.

When using drones to monitor nest sites, it is vital to minimise disturbance. More tips for avoiding disturbance can be found in the Wildlife disturbance section.

There's a lot of interest in using machine learning to count species in drone photographs. The accuracy of this technique is currently unknown. However, CDMU plan to explore this avenue in 2020.

Archaeology

While the detail captured in drone imagery is generally not good enough to identify new archaeological features, there are potential uses for drones in this area. The Digital Surface Model (DSM) can be useful for understanding archaeological features. To collect images that can be used for an archaeological DSM, surveys should be done in the winter (November to April), when the vegetation has died back, and the bracken has been crushed by snow. During particularly dry conditions, buried features can become more obvious, as the overlying vegetation tends to dry out more easily.

Drones can also be useful for quickly assessing if, and where, habitat management needs to be done in the vicinity of archaeological features. In less accessible areas, this may be quicker and easier than a manual survey. It also helps avoid unnecessary disturbance to historic monuments.

Data Management

Data storage

A key challenge for all frequent drone users is how to store and manage your data. If flying regularly the amount of data produced can be huge. The volume of raw data produced from a single mission can easily exceed several GB. There are 3 types of data you need to store for each flight:

1) Raw images/video captured by the drone
2) Any processing products (e.g. orthomosaics, DSMs, point clouds, processing project files)
3) Metadata (flight time and date, location, mission plan, flight log, etc.)

In most cases the processed products will be smaller than the raw imagery used to create them. It is always worth holding onto the raw imagery used, as the processes may need to be rerun with different parameters, or possibly in the future with new advanced software. It is recommended that raw imagery from unsuccessful flights is deleted to free space. There is currently some capacity for CDMU to store raw imagery and the associated processed products. These are searchable through our Spatial Data Catalogue. Orthomosaic images can also be uploaded to Merlin. If images are being stored locally, we recommend using external drives with a backup copy, if possible.

It is also worth considering whether non-confidential images should be shared externally. OpenAerialMap provides a free, open source platform for sharing aerials with the global community.

Naming conventions and folder structure

Every time you fly a drone and capture imagery for mapping, you are potentially collecting several hundred images. These images can then be processed to produce a combination of products including orthomosaic aerial images, digital surface models (DSMs), 3D textured meshes and point clouds. Suffice to say, it's all too easy to get your data in a mess. When the data become disorganised, it can become difficult to find the information you need, or to recall which aerial imagery belongs to which flight. This situation can be avoided by following some simple file naming conventions, and using a standard folder structure. It is advisable to save a copy of the flight log with the images.

Ideally, everyone at RSPB will follow the same folder naming convention. This way it will be easy to find and share data internally, between reserves, regions and countries. Although it's still early days and this convention is subject to change, our current recommendation is:

Top_level_folder\Broad_area_(e.g._Reserve_name)\Specific_location_YYYYMMDD_HHMM

Where 'YYYYMMDD' is the year, month and date that the images were taken, and 'HHMM' is the time at which the first image in the series was taken. Spaces and special characters should be avoided at all times.

This folder should contain an 'Images' folder where you should save your images. The processed products, e.g. the orthomosaic, should be stored in an adjacent folder called 'D2M_project' if Drone2Map is being used. For example:

Drone_Data\Haweswater\Gouther_Crag_20170504_1126\Images
Drone_Data\Haweswater\Gouther_Crag_20170504_1126\D2M_project

Recommended file structure for drone data. Image source: CDMU

Recording metadata

Metadata is simply data about data. It should provide an overview of what the data are. Metadata helps us to understand and make sense of the data we are working with. At the most basic level, recording metadata means that we have a record of where we've flown, at what times, and who the pilots were should we need to get in touch. Knowing how previous images were collected, will help us collect comparable images in the future.

Some of the metadata can be retrieved retrospectively from the images themselves e.g. date, time, location and camera type, but others must be recorded in the field e.g. pilot, weather and wind speed. Other elements will need to be captured in the field. The pre-flight checklist will collect most of the required information (see Appendix II: Pre-flight checklist and flight log).

Basic metadata for the flight data held by CDMU can be found in our Spatial Data Catalogue. Where additional flight information is available, details are recorded in a metadata index. This is maintained as an Excel workbook and records key information such as the date, time, pilot and number of images taken, as well as some additional information such as wind speed and cloud cover if known. This is available to anyone at RSPB. If you'd like details of your drone flights to be added to this metadata index, please contact CDMU.

Drone data on Merlin

Drone imagery can be added to Merlin. They can be found by selecting the Imagery option on the Query tab. See this video. To help you find the images, the grid reference of the imagery can be found in Merlin's metadata. The images on Merlin are orthomosaics, created from many individual drone images. CDMU can upload your drone imagery to Merlin. You will need to provide either the raw imagery, or a georeferenced orthomosaic, created in image processing software, such as Drone2Map.

Other topics

Outstanding things people have suggested we include:

- The trade off between a heavier camera with better resolution, and flight height/ disturbance
- Quality screening

Appendix I: Workflow – Do’s and Don’t’s

Advance preparation for the flight

- Read and understand the Code of Practice (RSPB code of practice B09)
- We are not licensed to use images collected by RSPB drones for commercial gain. This includes promotion and publicity.
- Obtain landowner’s permission before flying.
- Do not fly unless you have received training, in person, from an authorised instructor.
- Follow the protocols regarding signing out and returning the drone, including filling out the signing-out book.
- Ensure drone batteries and hand-set batteries are fully charged, and are not cold.
- Ensure tablet is fully charged.
- Ensure that the drone and all associated firmware have all the most up-to-date, stable firmware.
- Download basemaps for your flight area.
- If planning to use the images for GIS, plan a flight path with an appropriate level of image overlap using a mission planning app.
- Don’t fly in the fog or rain, or in winds over 20mph (or at or above Force 5 “Fresh Breeze” on Beaufort scale)
- Plan to fly at times of day when you won’t attract too much attention e.g. early morning at busy sites.
- Wear a name badge to identify you as an RSPB operative.

On-site preparation

- Get into location and check for hazards, particularly overhead wires, trees, people, water. Choose a site that is open which will provide safe a Return To Home (RTH) location, i.e. flat, and as far from trees water as possible.
- Make sure you know how to use the emergency Return To Home (RTH) function.
- Agree who’s flying and talk through your flight-plan with you flight buddy.
- Switch your personal mobile off, or put into aeroplane mode.

- Make sure the microSD card is in the camera, and the gimbal clamp and lens cap are removed.
- Make sure the antenna is in the receiving position.
- Switch on controller, drone, and then tablet in that order.
- If high GIS accuracy is required, set up Ground Control Points (GCPs), using appropriate marker points and recording their fixed locations.
- Open the Flight Control or Mission Planning app, and ensure the drone is ready to fly.
- Carry out compass calibration if necessary.
- Position drone for take off on top of the box – not in wet or long vegetation.
- Check camera lens is clean.
- Check for hazards again – particularly presence of people.
- Check drone battery level % is good to go on the Flight Control or Mission Planning app.
- Launch the drone and carry out flight to your pre-agreed plan. Don't forget to record stills, or movie images, as appropriate.

General in-flight advice

- Start high and drop down over points of interest – keep an eye on birds for potential disturbance at all times.
- Keep drone orientated away from you – i.e. fly out using right control stick, and move across to where you need to be and reverse back to home all on the right stick, rather than turn around with the left and fly back home forwards, as the left and right levers will operate in opposite directions.
- Do not hover lower than 12m (40ft) over nesting birds – higher may be completely adequate.
- Always maintain line of sight with drone.
- Don't fly it over roads.
- Keep an eye on battery levels at all times and return when no lower than 30% (a warning alarm will sound at this point and RTH function would soon be initiated automatically.

Landing

- Be aware that RTH function may not bring the drone back to exactly where it took off. Ideally override the RTH and land manually, with your flight buddy catching the drone.

Handling and analysing data

- Copy and save the images into an agreed location, and delete the images from the microSD card, and replace the card in the camera.
- If you plan to use your images for GIS, and your camera doesn't have GPS capability, save a copy of the drone flight log with the images. This will be used to retrospectively georeference the images.
- To mosaic the images in GIS, import georeferenced images (and flight log) into photogrammetry software e.g. Drone2Map. Optional products include orthomosaic aerial images, digital surface models (DSMs), 3D textured mesh, 3D point cloud.

Appendix II: Pre-flight checklist and flight log

Flight log: details

Pilot	
Drone	
Date	
Location	
Goal	

Batteries

Battery no.	
Charge before	
Charge after	

Mission

Distance	
Altitude	
File name	
Time depart	
Time landing	
Total time	

Camera

Camera model	
Trigger method	
Trigger interval	
Folder name	
Other relevant info	

Checklist

This serves as a guideline only, and needs to be modified relevant to the drone you are flying.

Drone

- ❑ Battery correctly installed
- ❑ Battery charge >75%
- ❑ Cables secured
- ❑ Recently calibrated
- ❑ Props installed in correct orientation
- ❑ Props checked for damage
- ❑ Attachments secured

Ground Station

- ❑ Controller charged
- ❑ Tablet charged
- ❑ UAV connection to controller
- ❑ Controller connected to tablet
- ❑ Default altitude set
- ❑ RTH altitude set
- ❑ Max altitude set
- ❑ Mode set to stabilise
- ❑ GPS satellite number >= 4
- ❑ Check mission
- ❑ Check mission speed
- ❑ Waypoints correctly set
- ❑ RTH set for connection loss
- ❑ Mission uploaded
- ❑ Antenna orientated correctly

Drone

- ❑ Level on ground
- ❑ Check props are secure

Camera

- ❑ Recently calibrated
- ❑ Securely connected
- ❑ SD card inserted
- ❑ Powered
- ❑ Settings matched to mission
- ❑ Settings written down
- ❑ Camera running

Conditions

(Only fly if all of these are met)

- ❑ No precipitation
- ❑ Light to no wind
- ❑ Area clear of people and vehicles

Appendix III: Glossary

Acronyms and initialisations

CAA Civil Aviation Authority

DJI Dà-Jiāng Innovations (drone manufacturers)

DSM Digital surface model

ESRI Earth Systems Resource Institute (creators of GIS software)

Exif Exchangeable image file

FPV First person view

GCP Ground control point

GIS Geographic information systems

GLONASS Global Navigation Satellite System

GPS Global positioning system

GSD Ground sampling distance

IMU Inertial Measurement Unit

LiDAR Light detection and ranging

NDVI Normalised difference vegetation index

NIR Near infrared

RRP Recommended retail price

RTH Return to home

RTK Real time kinematic

SFM Structure from motion (a.k.a. 'photogrammetry')

UAV Unmanned aerial vehicle

VARI Visible Atmospherically Resistant Index

VTOL Vertical take-off and landing

General terms

Aerial imagery – Images acquired by drones or satellites

Algorithm – computer code with instructions for solving a problem

Aperture – a hole through which light travels, e.g. the opening of a camera

ArcGIS Pro – GIS software created by ESRI

ArduPilot – creators of open source drone software

Barometric altimeter – a device for measuring altitude, using atmospheric pressure

Beaufort scale – a scale for measuring wind speed

Classification – grouping similar things together, e.g. identifying land cover types from aerial images

Digital surface model (DSM) – a model showing the elevation of the heights of objects

DJI GO – firmware for operating DJI drones

DJI GS Pro – mission planning firmware for DJI drones

Drone2Map – software for merging drone images into a single, composite image, created by ESRI

Drones Made Easy – creators of the Map Pilot mission planning app

eBee – a drone model created by senseFly

eMotion – mission planning software for senseFly drones

ENVI OneButton – software for merging drone images into a single, composite image

Exif data – a metadata standard used to define the properties of images

Firmware – a computer program used to control a device's hardware

First person view – a feed of the drone's view

Fish-eye lens – a wide angle lens, with high distortion, used to create panoramic views

Flight Control software – piloting software for drones

Flight log – the record of the key information about a flight

Focal length – the distance between the lens and sensor, e.g. in a camera

Geographical Information Systems (GIS) – a system for capturing, managing, manipulating and analysing spatial or geographic data

Georeferencing – assigning geographic information to an image, so that it can be mapped in GIS

Gimbal – a pivoted support for keeping a device level

GLONASS – high precision GPS satellite system

Ground control point (GCP) – reference ground truth data for high accuracy geolocation

Ground sample distance (GSD) – the size of an image pixel on the ground

Hardware – physical components of a computer system

Hyperspectral – many wavelengths, across the electromagnetic spectrum

Inspire – drone model made by DJI

LAS – a suite of tools for processing LiDAR data

LiDAR – a surveying technique that measures distance using laser light

Li-Po – lithium polymer battery

Map Pilot – mission planning software created by Maps Made Easy

Mavic – drone model made by DJI

Merlin – RSPB's internal GIS system

Metadata – a description of data, identifying its key properties

Mission planning software – software that automates drone flight, ensuring images are collected at regular intervals

Mosaic – the output of joining together multiple images taken on a flight
Multi-rotor – a style of drone with several propellers
Multispectral – a limited number of wavelengths, across the electromagnetic spectrum
Nadir – looking directly down
Normalised Difference Vegetation Index (NDVI) – an index for measuring vegetation health
Oblique – at a sloping angle
OpenAerialMap – an open service providing access to openly licensed imagery
OpenDroneMap – an open tool for processing drone data
Orthomap – aerial images corrected to a constant scale
Orthomosaic – the output of joining together multiple images, and corrected to a constant scale
Orthorectified mosaics – mosaic images that have been geometrically corrected to a constant scale
Parrot Sequoia – a multispectral camera
Phantom – drone model made by DJI
Photogrammetry – the science of making measurements from photographs
Photomap – the output of joining together multiple images taken on a flight
Photoscan – software for merging drone images into a single, composite image, created by Agisoft
Pix4D – software for merging drone images into a single, composite image
Point cloud – 3D points, representing the surface of objects
Positional accuracy – a measure of how well the position of a map represents the objects on the ground
PrecisionMapper – an open tool for processing drone data
Resolution – the size of an image pixel on the ground
senseFly – drone manufacturers
Sensor – an electronic component that measures changes
Software – a set of computer instructions
Spectral reflectance – the unique way that a surface reflects the electromagnetic spectrum of light
Spotter – a person, in addition to the drone pilot, who keeps an eye on the drone during a flight
Stereophotogrammetry – estimation of 3D coordinates from photographs
Structure from Motion – a photogrammetric technique for estimating 3D structures
Tetracopter – a drone with 4 propellers
Textured mesh – a 3D surface created from a point cloud
Unmanned Aerial Vehicles (UAVs) - drones

Version Control

Version	Date	Change Summary
1.0	28/09/2017	
1.1	11/10/2017	Small corrections plus contributors section added
1.2	10/11/2017	Naming convention and file structure for data management updated
1.3	06/02/2018	Merlin Imagery tab Drone assist app Advantages to snow cover Phantom 4 Pro Plus issue with external software
2.0	30/03/2020	General refresh and update based on knowledge acquired over the last couple of years Checked links Updated CAA regulations, drone model advice including Yuneec, sensor advice (including thermal), classification advice, hydrological modelling advice, and nest survey info