TECHNOLOGY FOR ENVIRONMENT OBSERVATION WITH DRONES

BSB-884 - "JOINT MONITORING FOR ENVIRONMENTAL PROTECTION IN BSB COUNTRIES"- BSB ECO MONITORING

WORK PACKAGE 1

SMART ENVIRONMENTAL MONITORING AND OBSERVATION

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Contents

INTRODUCTION 3

SMALL DRONES AND ENVINRONMET OBSERVATION 4

DRONE SURVEYING TYPES 7

KINDS OF DELIVERABLES THAT CAN BE EXPECT WITH DRONE SURVEYING 15

DIFFERENT TYPES CAMERAS FOR DRONES 20

PROCEDURES FOR ENVINROMENTAL MONITORING USING DRONES 31

REFERENCES 39

INTRODUCTION

The increasingly massive spread of small drones in the general market accompanies a rapid evolution of payload hardware and software. From photo/video to multispectral sensors, to environmental measurement devices, up to mechanical operation peripherals, even basic drones are being more sophisticated and miniaturized at the same time. The recent advent of minimal-sized professional drones is specifically to be taken into account, as it can make a substantial difference in terms of usability. There is some variability about the technical name assigned to these machines. This is generally due to the emphasis put on specific aspects of their nature or goals. The most widespread name of "UAV" (unmanned aerial vehicle) is very general and could apply to any machine able to fly without a crew; the focus in this case is on the aircraft itself. "UAS" (unmanned aerial system) generally implies that the vehicle is part of a wider system, involving a ground control station and possibly other components; "RPV" (remotely piloted vehicle), "RPA" (remotely piloted aircraft),and "RPAS" (remotely piloted aerial system), and their national language variants, emphasize that the vehicle is actively piloted from a remote station.

From a strictly ontological point of view, a difference is admitted between UAVs, in general, and RPAS. The latter are "remotely piloted" while the former could be any kind of aerial vehicle without an onboard crew. This includes then the types of platform, which can be taken into the air but with no control whatsoever, by a ground crew: free-flight balloons and airplanes, some types of rockets, etc. The distinction is substantial, but current use tends to converge on "UAV" in scientific contexts and "drones" among nonprofessionals, so we prevailingly stick to these two names.

Obvious applications can be found, from basic cartography and photogrammetry to specific fields of environmental studies and physical geography. The data acquisition capabilities of drones can also be applied to phenomena, which are interpretable in terms of human geography. From "thinking" of a specific survey to actually "doing" it, however, many details are to be put into place.

SMALL DRONES AND ENVINRONMET OBSERVATION

Environment observation includes, but generally goes beyond, the basic study of physical environment. It actually aims to comprehend spaces, territories, and cultural landscapes in their material dimensions and in some of their immaterial ones. This is possible inasmuch as the latter can be revealed or indicated by the configuration of material elements. The basic idea is that actions by human individuals and groups in their "espace vécu" are the result of choices derived – often unpredictably – from a combination of material and immaterial factors. Such complexity could be read by taking into account several epistemological and methodological approaches. By using drones – as any other survey tool – we can effectively investigate aspects of the physical space. In our analyses, such space can obviously appear as a physical environment or rather as an instance of that particular mixture of natural and artificial space that is called a cultural landscape. Anthropization of a certain site or region is induced (but not determined) by local conditions, on the one hand, and by interactions with the surrounding anthropized areas, at different scales, on the other hand. The area's inner functional system is to be integrated with lower level, peer-level, and higher-level systems. In the final analysis, however, people and communities first budget the aforementioned conditions and then drive their own territorialization process. By doing so, they establish and develop economically and culturally shaped spaces and networks of systems.

An important theoretical distinction was set, in geography, by the terms "space" and "place" (Tuan 1977). The former is a portion of Earth's surface that can be defined through sets of spatiotemporal coordinates; the latter can be understood as physical space(s) endowed, by the people who are in it, with experiential, existential, and symbolic values. Naturally, the symbolical texture of a certain space depends on the identity of the observer, whether the observer is a specific individual (drawing from her/his experience) or a member of a community referring to a specific shared system of heritage and values (Bignante 2010). Building from Vallega (2003) it becomes evident that the evolution of anthropized spaces can be expressed as a general feedback iteration among three mutually influencing dynamic nodes: perception, material transformation (also called "reification"), and regulatory organization. Through time, each node in the process evolves due to its inner mechanisms and by influence of the actions and reactions of the other two nodes.

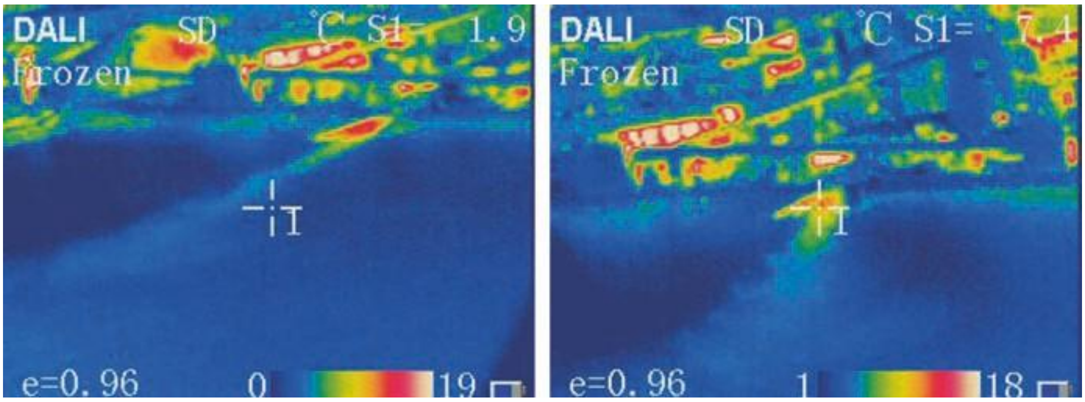
In summary, as it was stated before, human groups shape their places by adapting them to material conditions; nevertheless, this adaptation occurs based on perceptions and intentions of actors and decision-makers. The process takes place in relation – not necessarily in agreement – to formal or informal regulations. In this overall mechanism, culture is a major driver (Guarrasi 1992, p. 32).

In principle, we could observe how a certain space is configured from environmental and reification points of view. We could then use the acquired information to grasp knowledge on not only material and (possibly) regulatory status of the area but also, at least in some degree, about decisions and perceptions by communities in their living space.

As geographers observe spaces and places from above, regardless of the means they deploy for this purpose, phenomena can be analyzed according to at least three different levels of interpretation: material, functional, and symbolic. At the material level, nature, location, and purpose of specific elements can be analyzed. This basic type of interpretation is highly developed and widely applied in remote sensing. Analyses are because objects can be identified, measured, and examined in their physical nature.

At the functional level, material features of landscape are observed to interpret processes, flows, networks, and services. Analyses are conducted by recognizing –either directly or indirectly – status changes in different types of spaces, operational conditions of facilities and infrastructures, transitions in the availability of resources, usage of services, and variations in "footprints" produced as a side effect of human activity (Figs. 1.1 and 1.2).

At the symbolic level, landscape is surveyed in its material features in the attempt to identify elements of the presence and/or actions of a specific culture, whether this presence is current or past. In this case, analyses are oriented to recognizing specific material "markers" which can be associated to one or more systems of values, beliefs, and identities. From this point of view, drone observation can be thought of as a twofold knowledge acquisition means. Indeed, on the one hand, it can provide information and data about symbolical markers (also called "referents") present in the observed scene. On the other hand, the drone itself may provide information on priorities and perceptions of the users in reading their own landscape and cooperating to its observation (Turco 2010, pp. 263–266; Bignante 2010; Grainger 2017).



Figs. 1. and 2. Tracking human activity in the environment. Low-resolution thermal infrared images of the cooling water outlet of an electric power plant into the Tyrrhenian Sea. A plume of warm water is clearly recognizable as a low-altitude manned flying platform passes by the plant (Image: GREAL – European University of Rome)

Each geographical context can be understood either synchronically or diachronically.

In any case, however, a proper definition of the acquisition timing is necessary. It is worth noting, however, that especially in anthropization studies, diachronical analyses prove very useful toward a better understanding of evolution mechanisms.

Many of the elements and processes summarized above can be detected by the use of small drones. However, can UAV surveying and reconnaissance only achieve this? Obviously not. UAVs are just new, powerful, additional tools put in the hands of geographers. They can effectively do some parts of the job, but a full-blown knowledge about places goes far beyond the ability of systems to acquire data about spaces. Nevertheless, UAVs can provide researchers and operators with a large amount of information. Hence, better analysis and interpretation can follow wider, quicker, and cheaper (in all aspects) data acquisition.

DRONE SURVEYING TYPES

Surveying with a drone offers enormous potential to GIS professionals. With a drone, it is possible to carry out topographic surveys of the same quality as the highly accurate measurements collected by traditional methods, but in a fraction of the time. This substantially reduces the cost of a site survey and the workload of specialists in the field.

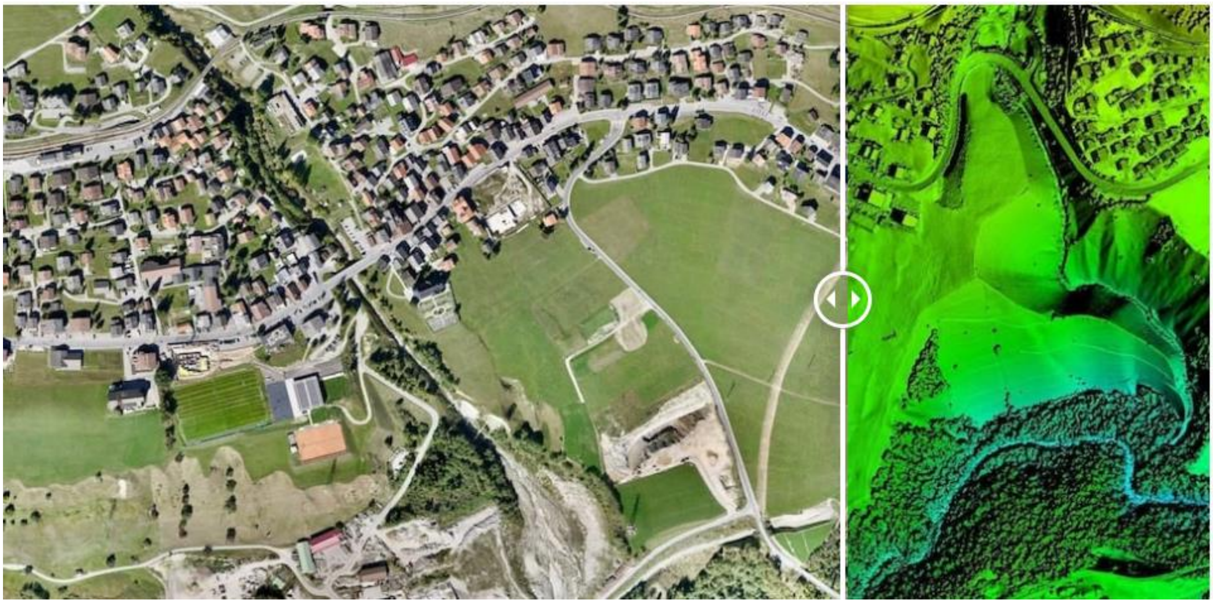


Fig.3 Orthomosaic and digital surface model created from aerial images taken by the WingtraOne surveying and mapping drone. (Image: By Wintgra, https://wingtra.com)

A drone survey refers to the use of a drone, or unmanned aerial vehicle (UAV), to capture aerial data with downward-facing sensors, such as RGB or multispectral cameras, and LIDAR payloads. During a drone survey with an RGB camera, the ground is photographed several times from different angles, and each image is tagged with coordinates.

From this data, a photogrammetry software can create geo-referenced orthomosaics, elevation models or 3D models of the project area. These maps can also be used to extract information such as highly accurate distances or volumetric measurements.

Unlike manned aircraft or satellite imagery, drones can fly at a much lower altitude, making the generation of high-resolution, high-accuracy data, much faster, less expensive and independent of atmospheric conditions such as cloud cover.

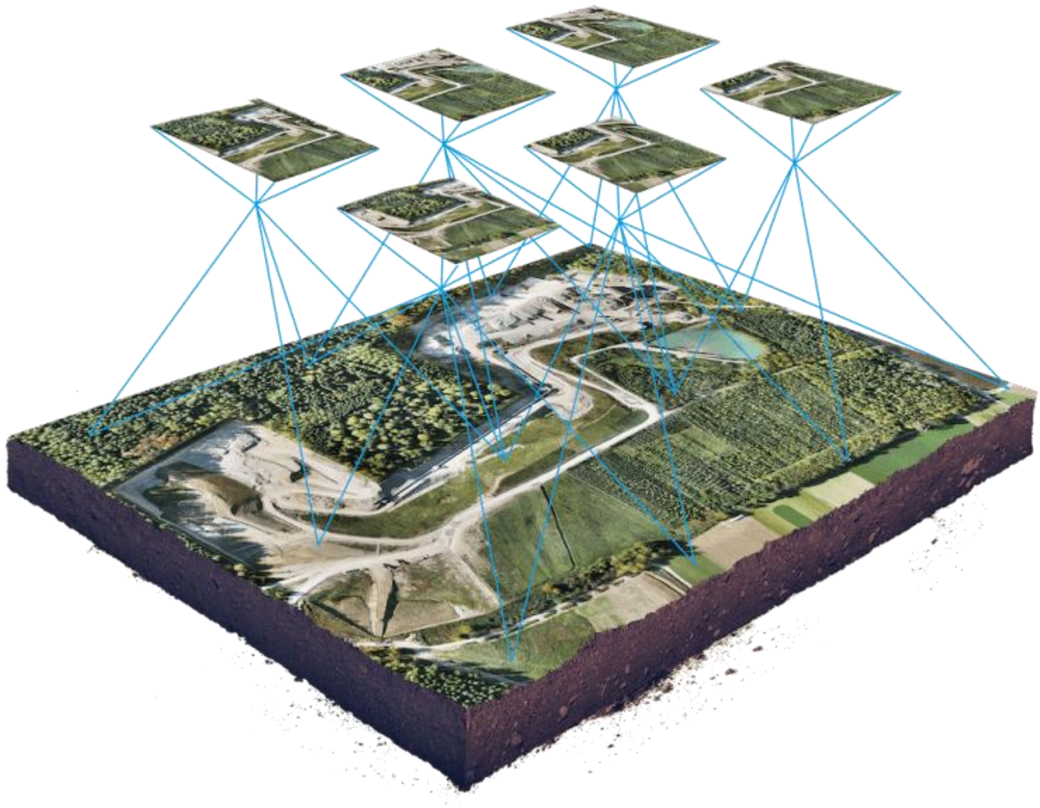


Fig.4 Photogrammetry combines images that contain the same point on the ground from multiple vantage points to yield detailed 2D and 3D maps. (Image: By Wintgra, https://wingtra.com)

Reduce field time and survey costs

Capturing topographic data with a drone is up to five times faster than with land-based methods and requires less work force. With PPK geo-tagging, you also save time, as placing numerous GCPs is no longer necessary. You ultimately deliver your survey results faster and at a lower cost.

Provide accurate and exhaustive data

Total stations only measure individual points. One drone flight produces thousands of measurements, which can be represented in different formats (orthomosaic, point cloud, DTM, DSM, contour lines, etc). Each pixel of the produced map or point of the 3D model contains 3D geo-data.

Land surveying / cartography

Survey drones generate high-resolution orthomosaics and detailed 3D models of areas where low-quality, outdated or even no data, are available. They thus enable high-accuracy cadastral maps to be produced quickly and easily, even in complex or difficult to access environments. Surveyors can also extract features from the images, such as signs, curbs, road markers, fire hydrants and drains.

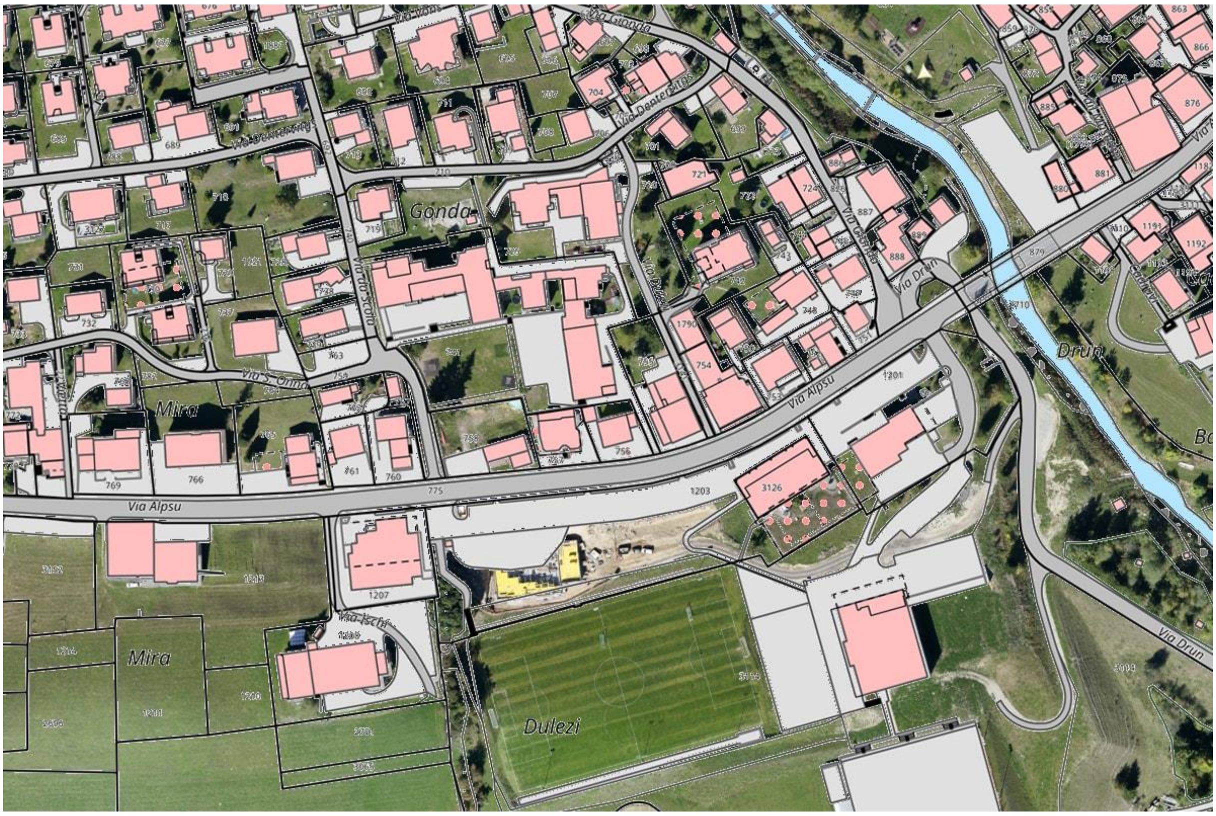


Fig.5 Cadastral map overlayed on aerial image. (Image: By Wintgra, https://wingtra.com)

After post-processing with a photogrammetry software, these same images can produce very detailed elevation models, contour lines and break lines, as well as 3D reconstructions of land sites or buildings.

Land management and development

Aerial images taken by drones greatly accelerate and simplify topographic surveys for land management and planning. This holds true for site scouting, allotment planning and design, as well as final construction of roads, buildings and utilities.

These images also provide the foundation for detailed models of site topography for pre-construction engineering studies. The generated data can also be transferred to any CAD or BIM software so that engineers can immediately start working from a 3D model.

As data collection by drones is easily repeatable at low cost, images can be taken at regular intervals and overlaid on the original blueprints to assess whether the construction work is moving according to plan specifications.

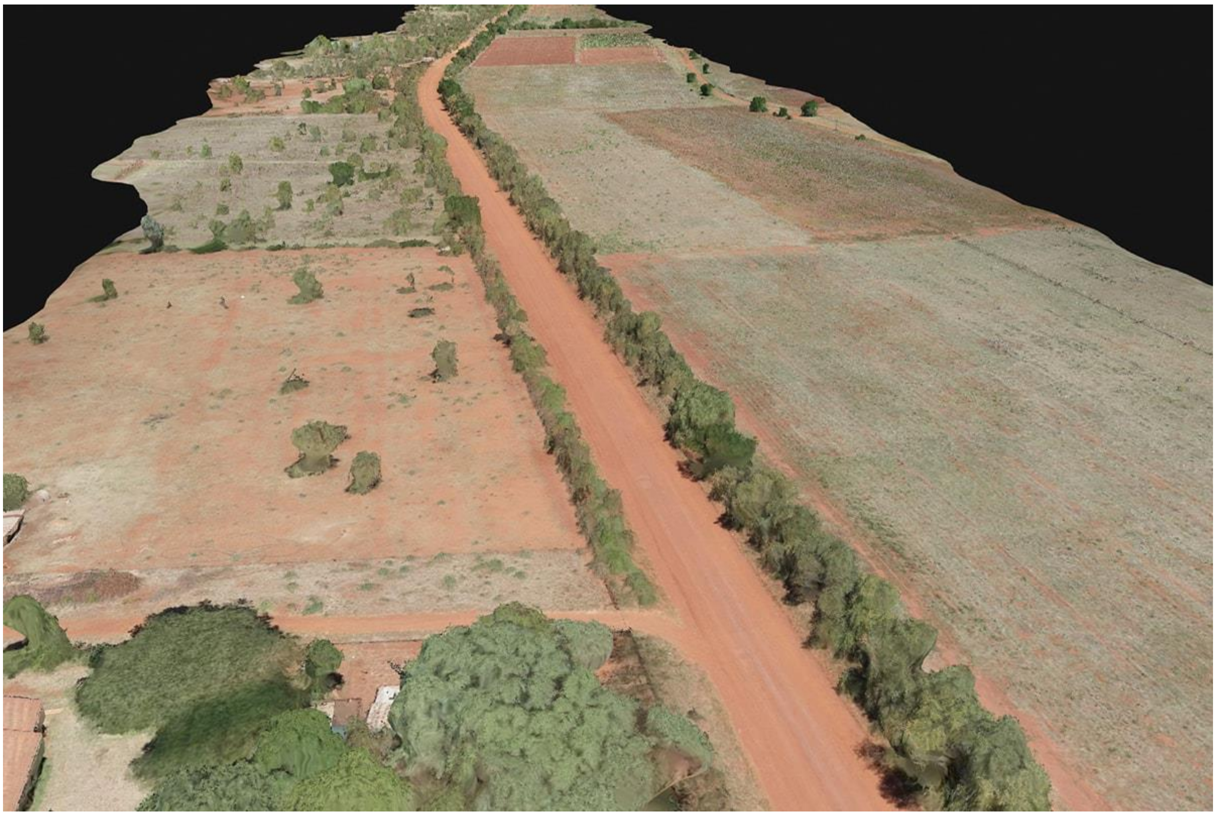


Fig.6 Survey of African road before construction planning (Image: By Wintgra, https://wingtra.com)

Precise measurements

High-resolution orthophotos enable surveyors to perform highly accurate distance and surface measurements.

Stockpile volumetric measurements

With 3D mapping software, it is also possible to obtain volumetric measurements from the very same images. This fast and inexpensive method of volume measurement is particularly useful to calculate stocks in mines and quarries for inventory or monitoring purposes.

With a drone, surveyors can capture many more topographic data points, hence more accurate volume measurements. They can also do this in a much safer way than if they had to manually capture the data by going up and down a stockpile. Since drones are capturing the data from above, operations on site won’t be interrupted. The short acquisition time enables capturing a site snapshot at a specific point in time.

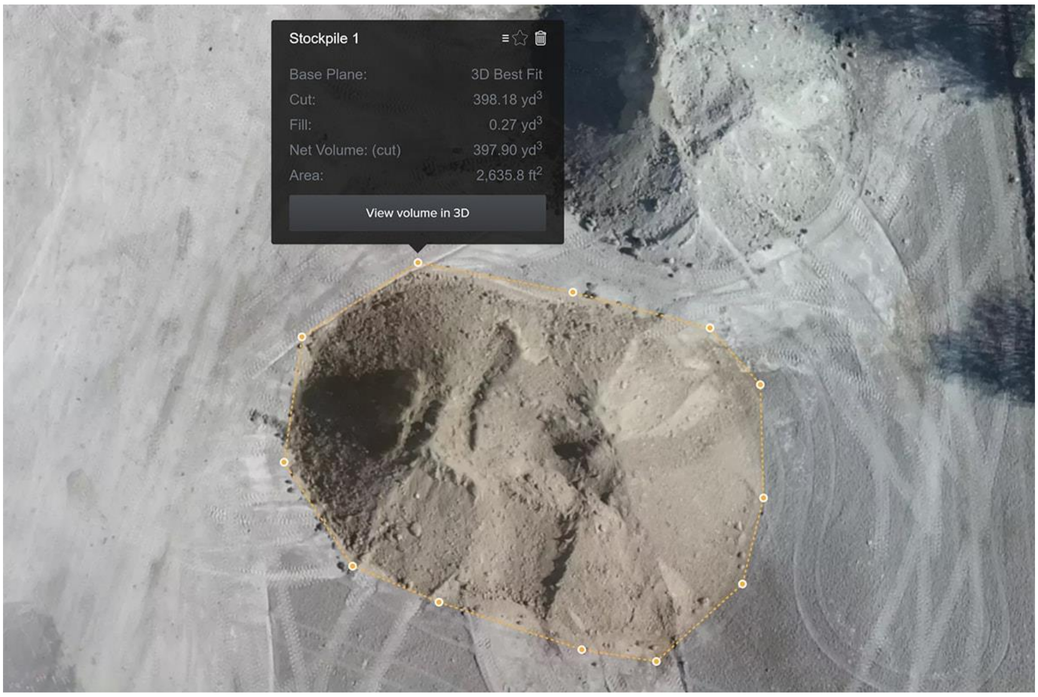


Fig.7 Stockpile volume measurement in a mining site (Image: By Wintgra, https://wingtra.com)

Fig.8 Volume measurement of a landfill in a Bahamas (Image: By Wintgra, https://wingtra.com)

Slope monitoring

With automated GIS analysis, it is possible to extract slope measurements from DTMs and DSMs generated by drone imagery. Knowing the steepness of the ground's surface, the areas can be classified and used for slope monitoring purposes, including landslide mitigation and prevention.

With orthomosaics taken at different times, it is possible to detect changes in earth movement and to measure its velocity. This data can help predict landslides and prevent potential damage to roads, railways and bridges.

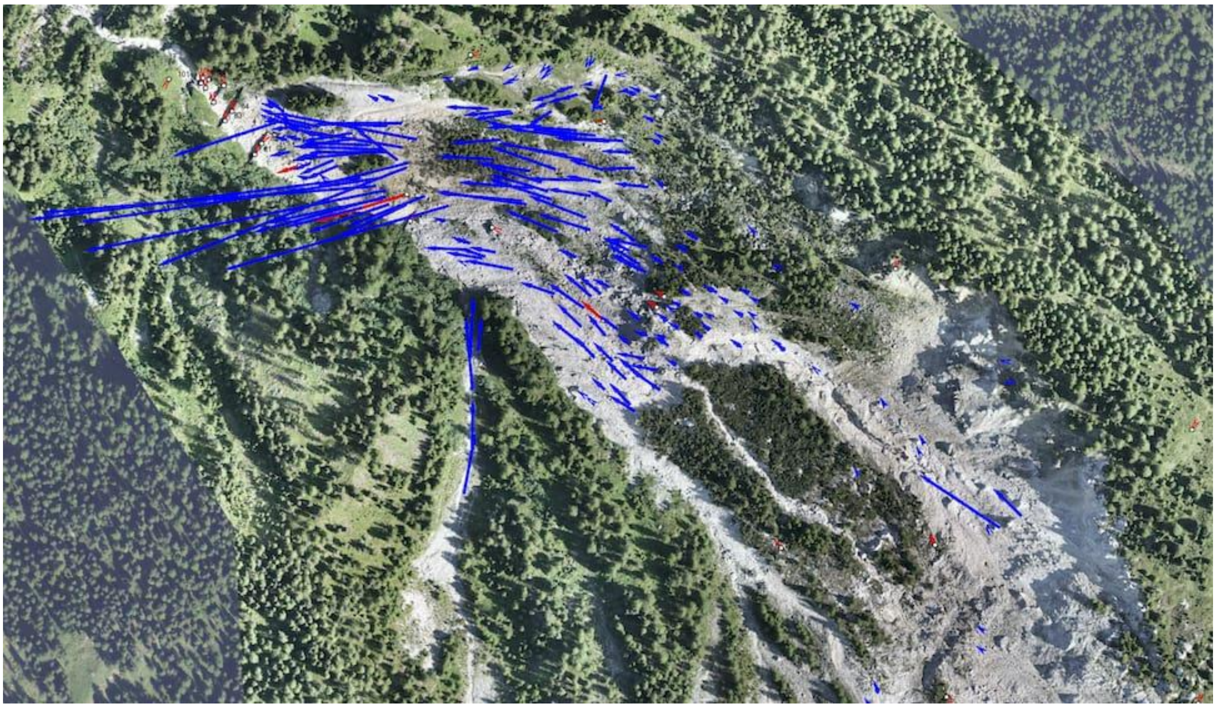


Fig.9 From this image, it is possible to compare which part of the terrain is moving faster or slower. The length of the strokes represents the velocity of the earth movement. The longer the stroke, the faster the earth movement. (Image: By Wintgra, https://wingtra.com)

Compared to traditional monitoring techniques, where sensors are placed on single points, drones enable more comprehensive data collection. Drones with PPK capability, which do not require laying out of multiple GCPs, are optimal for this application, since these areas are often hard to reach or even dangerous.

Urban planning

The development of increasingly dense and complex urban areas requires intensive planning and therefore time-consuming and expensive data collection. Thanks to drones, urban planners can collect large amounts of up-to-date data in a short period of time and with far less staff. The images produced in this way allow planners to examine the existing social and environmental conditions of the sites and consider the impact of different scenarios.

Fig.10 Zoning map overlayed on an aerial map of a mixed urban and leisure area . (Image: By Wintgra, https://wingtra.com)

Thanks to 3D models, buildings can also be easily overlayed onto their environment, giving planners and citizens an experimental perspective of a complex development project. 3D models also allow analysis and visualization of cast shadows and outlooks/views.

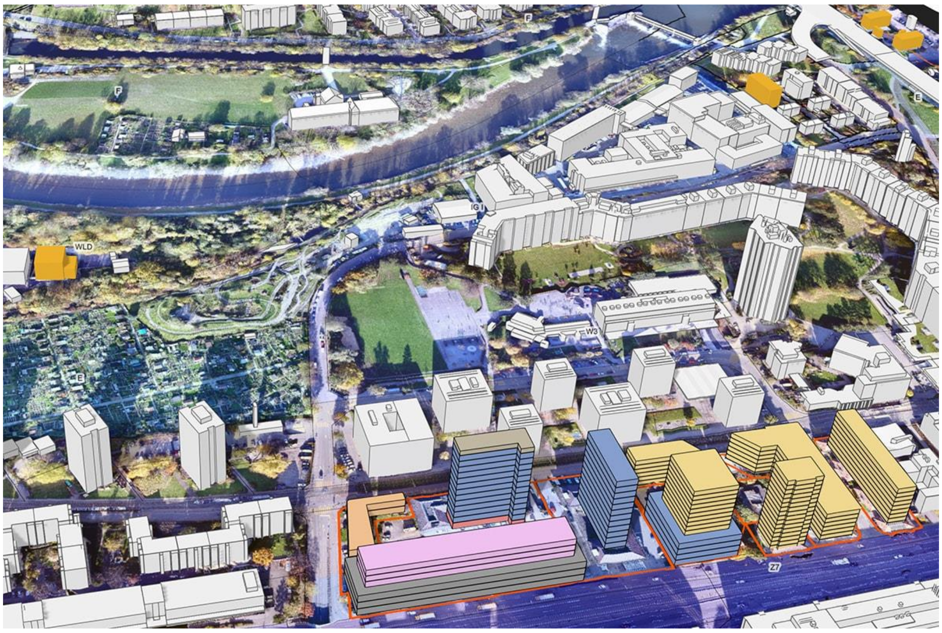


Fig.11 Aerial map with projected buildings in 3D on top . (Image: By Wintgra, https://wingtra.com)

KINDS OF DELIVERABLES THAT CAN BE EXPECT WITH DRONE SURVEYING

It depends on the camera or sensor and the software you are using for post-processing. RGB mapping cameras like the Sony's RX1R II or QX1 together with most photogrammetry software can produce the following data:

Fig.12 Orthomosaic maps. Drone images are corrected for image distortion and stitched together during post-processing to create a highly accurate orthomosaic map. Each pixel contains 2D geo-information (X, Y) and can directly procure accurate measurements, such as horizontal distances and surfaces. (Image: By Wintgra, https://wingtra.com)

3D point cloud

Fig.13 A densified point cloud can be generated from drone images. Each point contains geospatial (X, Y, Z) and color information. It provides a very accurate model for distance (slant and horizontal), area and volume measurements. (Image: by Wintgra, https://wingtra.com)

Digital surface models (DSM)

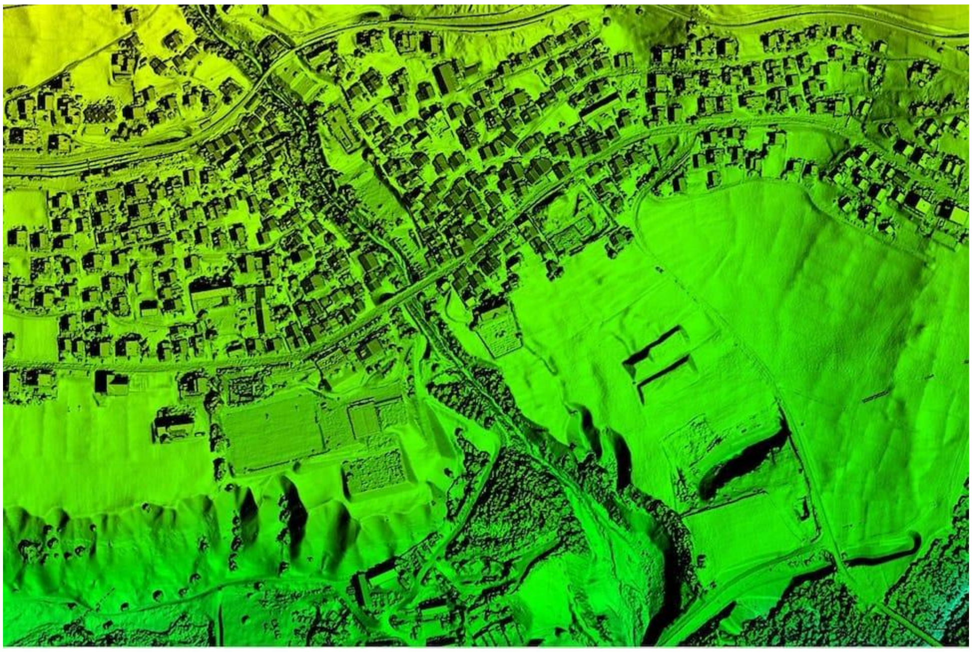


Fig.14 Drone images can also be used to create DSM models of the area. Each pixel contains 2D information (X, Y) and the altitude (Z value) of the highest point for this position.(Image: by Wintgra, https://wingtra.com)

Digital terrain model (DTM)

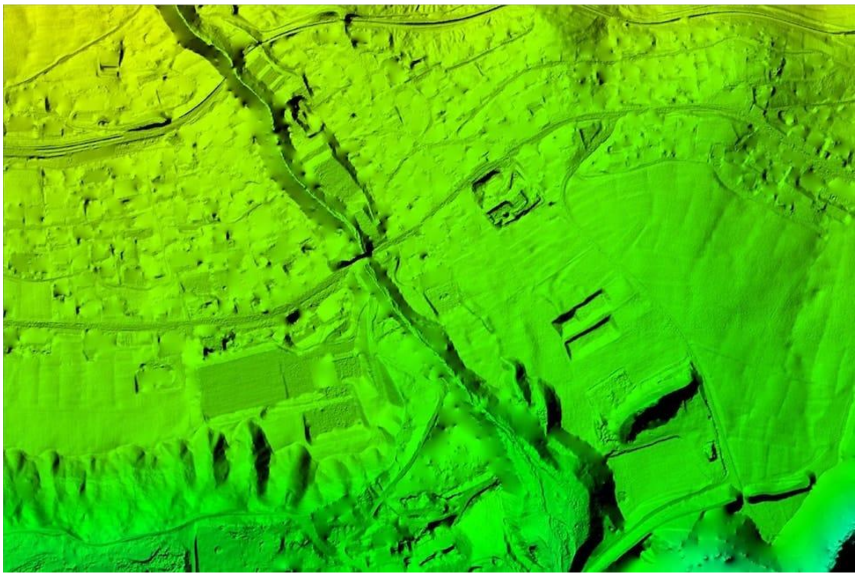


Fig.15 After filtering objects such as buildings, the drone images can be used to create DTMs with each pixel containing 2.5D information (X, Y, and Z value of the highest altitude). (Image: by Wintgra, https://wingtra.com)

3D textured mesh

Fig.16 The 3D textured mesh is a reproduction of the edges, faces, vertices and texture of the area shot by the drone. This model is most useful for visual inspection or for when external stakeholders or public involvement is essential for a project. (Image: by Wintgra, https://wingtra.com)

Contour lines

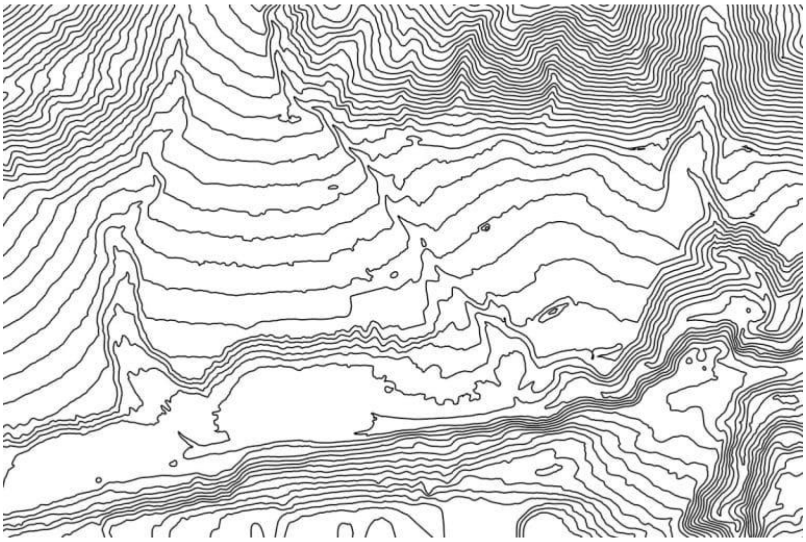


Fig.17 Depending on the project requirements, either the DTM or DSM model, with custom contour intervals, can be used to create a contour lines map, giving you a better understanding of the surface of the area shot by the drone. (Image: by Wintgra, https://wingtra.com)

Multispectral Imaging

A multispectral image is one that captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or detected via the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, i.e. infrared and ultra-violet. Spectral imaging can allow extraction of additional information the human eye fails to capture with its visible receptors for red, green and blue. It was originally developed for military target identification and reconnaissance. Early space-based imaging platforms incorporated multispectral imaging technology to map details of the Earth related to coastal boundaries, vegetation, and landforms. Multispectral imaging has also found use in document and painting analysis.

Multispectral imaging measures light in a small number (typically 3 to 15) of spectral bands.

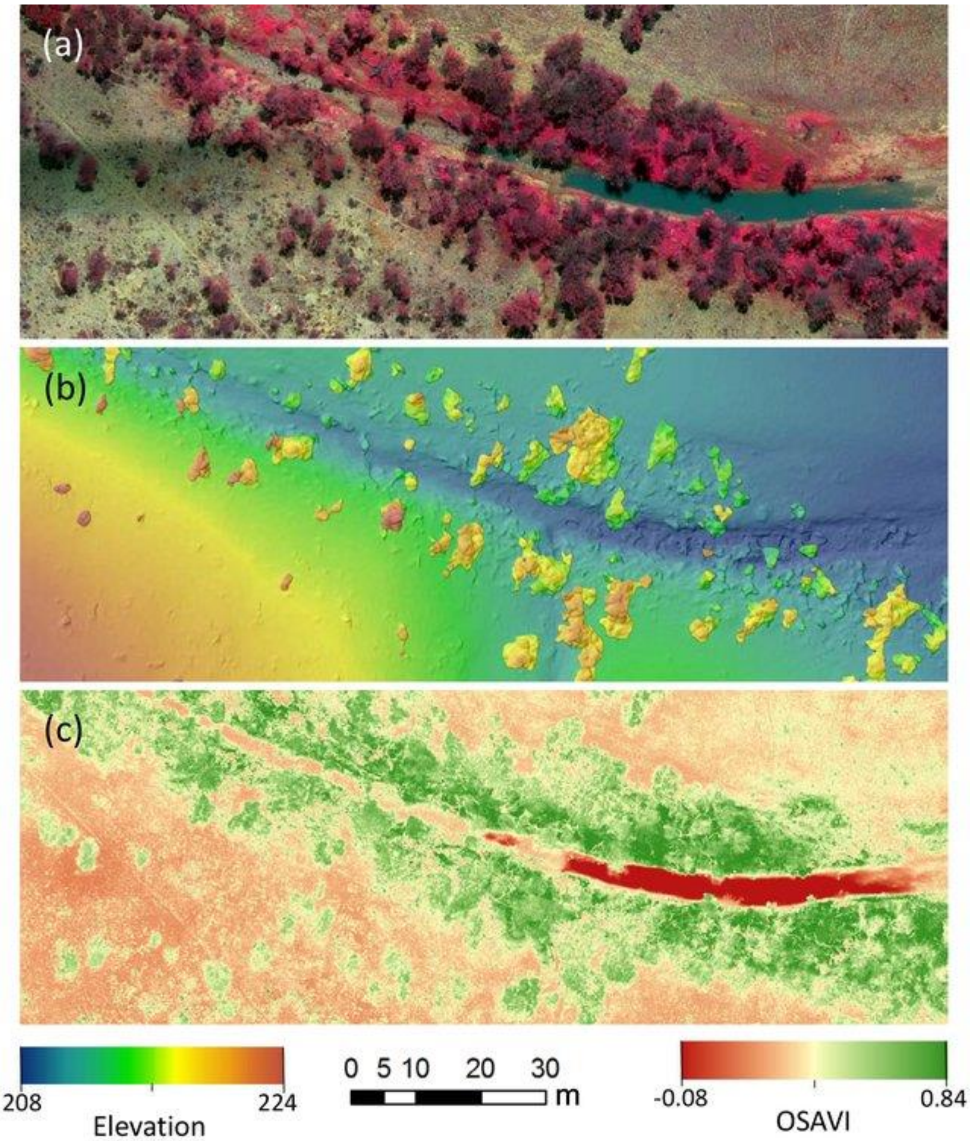


Fig.18 Employing a UAV to retrieve high-resolution multispectral information on the land surface for hydrology and related applications over an Australian rangeland site located near Fowler's Gap in New South Wales. Retrieved products include (a) a false-color infrared image, (b) a reconstructed digital surface model using visible imagery and structure-from-motion techniques and (c) an optimized soil adjusted vegetation index (OSAVI) derived from the 4-band multispectral image. Images were captured using a Mica Sense/Parrot Sequoia sensor on-board a 3DR Solo quadcopter. The UAV was flying at a height of 40 m, providing a ground sampling distance of approximately 3 cm. Imagery provided by the University of Tasmania's TerraLuma Research Group.

DIFFERENT TYPES CAMERAS FOR DRONES

In general, cameras can be divided according to their application into two types - amateur and professional. Amateur cameras are mainly built into the body of the drone cameras have smaller dimensions and weaker characteristics. Amateurs and semi-professionals for photo and video shooting of sports and other outdoor activities, for training, as a gift or just for fun, use them. The cameras are mounted in rotor drones with up to four rotors and are often equipped with FPV goggles (real-time transmission) or are part of RTF drones - fully assembled and ready to use (with a "follow me" function.)

Amateur cameras, as part of the drones, cannot be replaced and cannot be considered as separate from the drone. Therefore, they do not disturb the aerodynamics of the drone and are not required to have an aerodynamic shape. The trend in their development is to increase video and photo characteristics, minimize their size and weight. They increasingly support 1080P HD format of aerial photos, adjustable angle up to 120 °, 2MP WIFI high quality video in real time directly from the remote control. They allow you to make a perfect selfie from a bird's eye view.

Professional cameras are used in solving problems in science and business, as well as for military activities. They are often self-contained, can be replaced by a drone and generally have very good technical characteristics.

Fig.18 Professional camera from DJI from the ZenmuseX series, used for professional photography and cinematography. 24 MP sensor, 4K Ultra HD: 3840 × 1572, 30p, ISO100 –25600 for photos and 100 –6400 for video, speed 1 / 8000s –8s

Fig.19 YuneecCGO ET thermal camera, used for night photos and thermal images and video recording. 12MP sensor, shooting resolution 1920 x 1080p 30 fps, sensitivity 100-12800 ISO, temperature sensitivity from -10 ° to 180 °, LWIR wavelength: 8 µm -14 µm

Fig.20 The Snoopy LidarUSA LIDAR camera, shot at 700,000 dots / s, has 32 individual lasers with a range of -40 degrees vertical and 360 degrees horizontal flax, +/- 2 cm accuracy and 100 m range

Another indicator by which cameras can be subdivided is the spectral range in which they operate (register). They are divided into: 1. Cameras in the optical range (RGB cameras) The characteristic of these cameras is that they register video and photo recording in the visible range of the electromagnetic spectrum - red, green and blue. This group includes almost all cameras for amateur drones (for shooting in real time, for and video "selfies", etc.).

Fig.21 Quadcopter Eachine E50 with WIFI real-time video transmission, camera: 2MP, 720P, video and photos;

These are video cameras and cameras for drones, shooting panchromatically in the visible range of the spectrum (Fig. 4). Or in spectral channels blue, green, red.

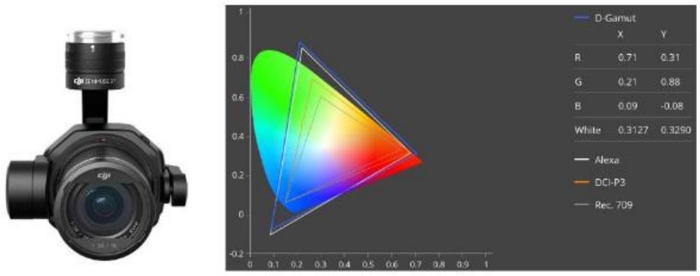


Fig.22 Drone camera for professional video recording ZENMUSE X7

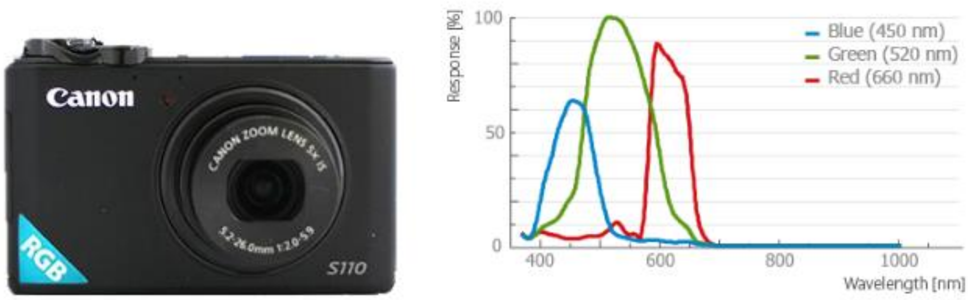


Fig.23 CanonS110, 12 MP RGB Spectrum Camera, for receiving images in the visible spectrum in three channels: blue, green and red

Multispectral (NIR, Green, Red, Red Edge) cameras

Multispectral images are a very effective tool for assessing the state of the environment (soil productivity, analysis of plant condition, land-water boundary, etc.). The study of the state of the environment with the naked eye is very limited and irrational.

Multichannel (multispectral) imaging technology and the combination of them allows you to see much more than with just the "naked eye". It is oriented to the characteristic spectral reflectivity characteristics of plants and the ability to calculate different vegetation indices (NDVI, NDRE, etc.).

This data is also used in geology, geomorphology, archeology, etc. using libraries with spectral reflectance characteristics of minerals and rocks. In agriculture, data from multispectral cameras (Fig. 6-10) -multispectral images have a number of advantages:

-Enable to work with spectral data from different spectral channels (NIR, Green, Red, Red Edge, etc.);

- Identify pests, plant diseases and weeds;

-Can optimize the use of pesticides in cultivated plants by early detection of pests and diseases;

-Optimization of fertilization by detecting nutrient deficiencies;

-Easy and optimization of crop rotation (crop rotation);

-Determination of crop density and density;

-Prediction of crop yield; controlling irrigation by identifying areas where water stress is suspected;

One of the leading agricultural cameras (sensors) in the sector are those of Sentera (Fig. 6). Sensors are fully adaptive, which allows the use of both visual, multispectral data channels, and calculated spatially and radiometrically accurate, plant indices NDVI, green NDVI and NDRE. Quad sensor can measure key indicators of chlorophyll in crops. These cameras give a real-time view of the state of the crop.

Fig.24 Sentra High Precision 4-channel multispectral camera

The Parrot Sequoia camera (Fig. 7) is one of the smallest and lightest multispectral cameras for the drone market to date. It is specifically aimed at capturing crops in the four defined spectral channels, in the visible and near infrared zones of the RGB spectrum plus. The camera uses two sensors. One captures the reflected solar radiation, and the second, mounted on the back, registers the incident solar radiation in the same spectral channels. This allows the received data to be calibrated during the recording.

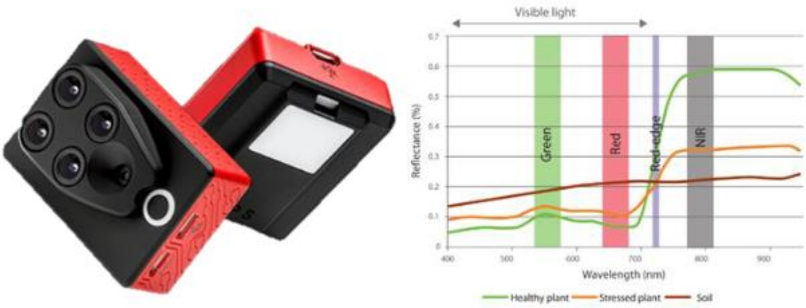


Fig.25 4-channel multispectral camera Parrot Sequoia

The Canon S100 NIR multispectral camera (Fig. 8) is capable of capturing images in the red and NIR (near infrared) regions of the spectrum. The original IR (infrared) blocking filter has been replaced by a high-quality dual-band pass filter, which allows the red and NIR spectra to reach the sensor inside the camera.

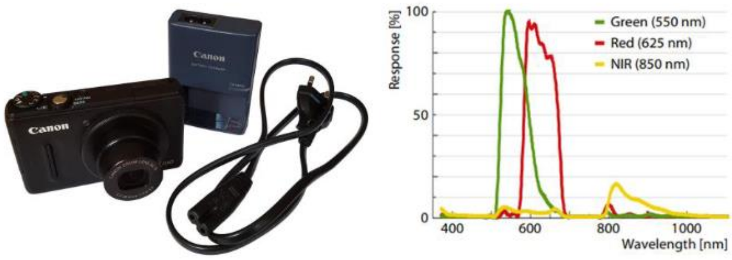


Fig.26 Canon S100 NIR multispectral camera

The ADC Lite multispectral camera has a 3.2-megapixel sensor optimized for detecting wavelengths in the visible, greater than 520 nm to 920nm and in the near-infrared region of the spectrum (Fig. 9).

Fig.27 ADC Lite multispectral camera

The MicaSense Red Edge multispectral camera (Fig. 10) is a system for simultaneous registration in five separate spectral channels, allowing the creation of specially adapted indices. Integrating the two five-band cameras, RedEdge-MX and RedEdge-MX Blue, enables the most modern applications for remote sensing and vegetation research. The Airinov multiSPEC 4C multispectral camera is aimed at precision farming. Measures reflected solar radiation from crops in four different spectral channels: green, red, Red Edge and NIR.

Fig.28 RedEdge-MX and RedEdge-MX Blue multispectral cameras

Thermal cameras

Thermal cameras allow their use for rescue operations, firefighting, inspection of solar panels and electrical networks, monitoring of animal crops, inspection of buildings, chimneys, power lines, power stations, pipelines and night surveillance of settlements, etc. (Fig. 11 and fig. 12)

Fig.29 Application of thermal cameras

Fig.30 The Yuneec CGO ET thermal camera combines high light sensitivity for night photos and a temperature sensor for thermal images and video recording.

Fig.31 Thermal camera SMT18HT6 combines 18x optical zoom and 640 x 480 thermal imaging system

Fig.32 The thermal imaging camera DJI Zenmuse HT has been developed by FLIR. It provides high sensitivity (50mK) for 640/30 infrared shooting /sec.

Hyperspectral cameras

Hyperspectral cameras are characterized by shooting in very narrow spectral channels. They register the reflected solar radiation in the visible-near infrared (VIS-NIR) and medium infrared (SWIR), covering the spectral range of 400–2500 nm (Fig. 13).

Fig.33 Different types of hyperspectral cameras

Lidar Cameras

The use of LIDAR drone cameras in photogrammetry, 3D photogrammetry and LIDAR mapping is increasing rapidly. This is not surprising, as the use of an aerial surveillance drone is much more cost-effective than hiring an aircraft with photogrammetric equipment. Because drones are relatively inexpensive, many organizations will have their own "fleet" that, allows rapid exploration of large areas where needed.

Drones equipped with GPS, digital cameras and powerful computers (artificial intelligence) allow for research with an accuracy of 1 to 2 cm (Fig. 34).

Fig.34 Different types of LIDAR cameras

Drone Camcorders

The camcorders feature incredible 4K / Full HD 4: 2: 2 video and high-quality photos, have a compact, lightweight and easy-to-use lens-changing body and a optical image stabilizer (Fig. 15).

Fig.35 ZENMUSE X7 - DJI's professional ZenmuseX series cameras are widespread among professionals and enthusiasts in photography and cinema.

Fig.36 Rapture X8 Arri Alexa camera for professional cinematography

Other drone cameras

Ground penetrating radar (GPR) has been around for a long time, but in combination with an air system, it provides specific advantages such as increased air coverage, remote access and mapping, inaccessible or too dangerous for personnel areas (Fig. 16).

Fig.37 COBRA DJI Matrice600 Pro with georadar (GPR) uses real-time radar signal

U10 (Fig. 17) is a lightweight, highly sensitive gas detector based on laser spectroscopy with adjustable diode tuning (TDLAS), which allows rapid identification of methane from a distance of up to 100 mils with a concentration of up to 5ppm.m. Powered by the DJ SkyPort, the U10 can be seamlessly integrated with DJI Matrice 200 Series V1 and V2 platforms.

Fig.38 Laser detector for methane leakage U10

Conclusion

The wide variety of drone cameras determines the possible areas of application, and these are:

Forest management and planning; Agriculture and forestry; Flood modeling; Hydrodynamic modeling; Freshwater bathymetry; Pollution modeling; Mapping and cartography; Digital terrain models; 3D modeling and topography; Construction site monitoring; Construction and structural inspections; Urban research, urban planning; Coastline management and modeling; Transport planning; Oil and gas exploration; Quarries and open pit mining; Geological surveys for soil profiling; Archeology and cultural heritage documentation; Cellular network planning; Photogrammetry began to require the use of drones with LIDAR sensors; Corridor mapping: power line, railway line and inspection pipelines; Resource management; Mapping of underground infrastructures with georadars, etc.

PROCEDURES FOR ENVINROMENTAL MONITORING USING DRONES

Legal framework

The regulation of Unmanned Aerial Vehicles (UAV) has been an ever-evolving field with constantly ongoing development in recent years to keep pace with technology and the increasing popularity of UAVs with a variety of consumers. Currently, the regulation of UAV operations within Europe is still dependent on weight categories. According to regulation No 216/2008, platforms with maximum take-off mass (MTOM) of 150 kg and above are regulated by the European Aviation Safety Agency (EASA), whereas lighter platforms are to be regulated by the EU member states. This has led to a fragmentation within UAV regulation across Europe for the vast majority of UAV operations (EASA, 2018). National bodies such as the Civil Aviation Authority (CAA) in the United Kingdom (UK) develop regulations for example. While similar, regulations at national level have proved to vary in all compared variables (Stöcker et al., 2017).This limits cross-border collaboration within the EU as well as posing difficulties regarding manufacturing requirements for UAVs. The EU, as well as UAV operators and manufacturers within would greatly benefit from overarching regulations, especially for operating internationally. Currently, a new basic regulation has been proposed (see NPA 2017-05) and is under discussion between the European commission, council and parliament. Besides safe operations of UAVs through competency requirements and standardized risk assessment procedures for specific operations, this regulation should also address privacy and data protection. Member states will reserve the rights to designate no-fly zones and zones with increased restrictions for UAV operations. Alleviations may also be made by designating specific zones for operations and enabling model clubs for recreational operations. The large majority of scientific UAV operations will fall within the <150 kg weight category and therefore, as stated above, their regulation currently differs slightly throughout EU member states. Instead of listing these here we instead provide the UK specific regulations as an example, which has inspired and in turn been inspired by the regulations adopted by other member states. The CAA regulations represent an amalgamation of international, EU and domestic legislation. Key legislation for all aviation is laid down in the Civil Aviation Publication (CAP) 393 “Air Navigation Orderand Regulations” . Unmanned aircraft are divided into categories, differentiating between Small Unmanned Aircraft (SUA) with MTOM <20 kg, Light Unmanned Aircraft with MTOM >20kg and <150kg and Unmanned Aircraft with MTOM >150kg (and thus regulated by EASA). It contains only few articles relating to SUAs (article 94) and small unmanned surveillance aircraft (SUSA) (article 95) which includes any aircraft capable of data acquisition and is therefore of relevance to any scientific operation. Article 94 deals with basic safety requirements. It specifies the following:

1. No object may be dropped from an SUA to endanger any person or property.

2. The operator of the SUA may only fly if he is reasonably satisfied that the flight can safely be made.

3. Direct, unaided visual contact with the aircraft must be ensured at all times in order to avoid collisions.

4. If the aircraft weighs more than 7 kg excluding fuel, it must not be flown:

a.In class A, C, D or E airspace, unless air traffic control permission has been acquired.

b.Within an aerodrome traffic zone during its period of operation, unless permission has been acquired.

c.At a height of more than 400 feet (~120 m) above the surface.

d.For the purpose of commercial operations, unless appropriate certification has been acquired.

Article 95 details further regulations for SUSA, specifically distance constraints. Without permissions, SUSA must not be flown:

a.Within 150 m of a congested area.

b.Within 150 m of an assembly of over 1000 people.

c.Within 50 m of any vessel, structure or person not under the control of the operator.

d.Within 30 m of any person not under the control of the operator during take-off and landing.

Flight planning

Task definition:

The general objective of the research and thus of the flight is to be defined, in order to determine the best parameters in terms of:

- Spectral resolution
- Spatial resolution;

- Time of the flight during the day: this parameter is essential, for instance, in case the objects to be surveyed are tall and cast shadows over each other (e.g. trees, tall buildings), or when flying over water (Duffy et al., 2018);
- Platform to fly: fixed wing aircrafts can usually survey larger portions of land in comparison to multi-rotors (Duffy et al., 2018);
- Other flight parameters: for instance, for many agricultural applications images are acquired at nadir, while for photogrammetric surveys different acquisition angles are required.

Site assessment

The area to be surveyed should be identified with its geographical coordinates. In the first place, restrictions over the surveyed area should be checked:

- Permanent restrictions: these regards, for instance, military areas.
- Temporary restrictions: they are usually defined in case of a hazardous event (e.g. a wildfire) or in case of a security-related event (e.g. a G8 meeting).
- Restricted airspaces: these are areas including sensitive locations, for instance a nuclear or military facility. Special permissions are needed to fly over these airspaces.
- Other restrictions: these are country-dependent and include, for instance, natural and marine areas or bird conservation areas. Normally, each country makes a dataset of airspace restrictions available to the public or at least to the authorized pilots. In the second place, geographical features that might affect the flight should be identified: for instance, electricity towers, wires, trees, tall buildings. These may affect the flight planning. Thirdly, the size and morphology of the surveyed area must be evaluated: this will help in determining the best flight lines, the flight time and therefore the number of needed batteries, the necessity of a co-pilot to keep the drone in sight. In the case of a fixed-wing platform that needs a big space in order to take off, it is advisable to check that such a space is available, within or next to the surveyed area. Finally, other site characteristics should be kept in mind, including the possibility of an event involving a big number of people in or nearby the surveyed area, ongoing at the same time of the flight; the possibility of having public approaching the pilot and co-pilot, to be controlled with a cordon. The site assessment should be done with a

preliminary visit on the field and/or with the aid of other virtual instruments (e.g. USGS Earth Explorer, Google Earth).

Risk assessment and management

The procedure of risk assessment helps in identifying the possible hazards involved in the drone flight and, consequently, in managing them. Consequences of ill-managed risks may can involve damage to the aircraft or even to people. It is advised to make a list of the possible hazards (e.g. electromagnetic interference determined by the presence of an electricity tower), together with the potential consequences and the likelihood to happen. Moreover, it is good practice to establish emergency hover zones. It is essential to consider site-specific hazards, as explained in Duffy et al. (2018)

Planning of the flight and of the required equipment

Flight planning includes the definition of the following parameters:

- Waypoints: these are points on the ground, which need to be surveyed.
- Flight lines, with image front lap and side lap: it depends on the complexity of the surveyed site, especially with regard to tall objects or complex soil morphology. They will be planned so that all the waypoints are surveyed.
- Flight height: it depends on the platform, the desired spatial resolution and the presence of obstacles.· Flight time: it determines the number of required batteries and the necessity of splitting the flight into two or more parts.
- Take-off and landing zones: their size and characteristics can vary considerably when operating a multi-rotor or a fixed wing aircraft (Duffy et al., 2018).

These parameters must be determined also by keeping into consideration the site assessment: for instance, the presence of a tall tree might impose a certain flight height, just as if the presence of an electricity tower could determine a change in the flight lines. If the site assessment cannot be very accurate, a preliminary flight can be useful in providing the necessary information (see the case of the rainforest mentioned in Duffy et al., 2018).Several software packages are available to plan UAV flights by setting the preferential flight parameters (e.g. DJIFlightPlanner(DJI, 2016), eMotion (SenseFly Ltd, 2014)).A list of the required equipment should be compiled, taking into account: platform to fly; camera(s); batteries; repair kit; special clothing for the pilot and co-pilot; protection glasses or sunglasses for the pilot and co-pilot; instruments for ancillary measurements (see §6); toolbox; notebooks and/or logbooks. The flight planning should be discussed with all the members of the crew.

Flight preparation

Following recommendations are largely based on the ESI DroneLab operations manual (Cunliffe et al, 2017).

Weather forecast

Long-range weather forecasts will be acquired a week before each planned operation from the most reliable source, usually national. Ideally, a larger period would be designated within which operators and field personnel are flexible, and initial adjustments to the planned operation date and time could be made daily. For practical reasons this is not often possible. Once a date is fixed, the weather forecast is checked again 24 hours prior to the planned operation time, at which point the definitive go-ahead or cancellation is given. Operations are cancelled either if a safe flight cannot be guaranteed due to wind or precipitation, or if weather conditions are unfavorable for data acquisition. Wind speeds at which it is safe to operate vary strongly between systems, with multirotor UAVs generally able to cope with higher winds than fixed wing. In both cases, the manufacturer's recommendations should be followed. Gust speeds should be used as reference in place of average wind-speeds. Depending on the type of data acquisition and sensors used, high platform stability or constant, direct illumination may be required. This can be more difficult to judge and operations may be attempted despite non-ideal conditions, as long as safe operations are guaranteed.

Site permissions and notifications

To ensure lawful and ethical UAV operations, permissions of the landowners of any sites flown over and/or imaged should be acquired. Where possible, written consent should be obtained as a signature or by email so it is on record. If the site is within 5 km of an aerodrome traffic zone, explicit permission should be acquired from the air traffic control, for which the approximate coordinates; flight height and time of flight must be provided. To notify third persons of UAV operations, warning signs or additional people should be placed along public footpaths. Flights within restricted zones should be avoided wherever possible, as costly and time-consuming applications to the relevant authorities will have to be made.

Communications

Where operations take place close to controlled airspace, communication should be sought with the responsible air traffic control service, which can update the operator on any unforeseen activity. All relevant numbers as well as those of emergency services should be identified and recorded at the flight-planning stage. Communication must be guaranteed between all members of the team at all times, using either mobile phones or radios.3.4 Preparation of crew's equipment and clothing prior to the flight, the crew should take care of wearing suitable clothing, also according to the weather forecast. High visibility clothing indicating the member's role (e.g. "Pilot") is preferable. Crewmembers should always bring identification documents, as well as any other document proving that necessary flying permissions.

Preparation of the crew

With due anticipation, the crew members should be informed of:

-Objective and location of the flight

-Possible hazards at the time and location of the flight-Role they are assigned to

-Any other significant detail.

Flight procedure

In situ site assessment

Once on the site, the crew should check carefully:

- The presence of obstacles or hazards, on the surveyed site or in the neighboring area.
- The conditions of the takeoff and landing sites.
- The position of the sun, which should not affect the ability of the pilot and co-pilot to keep the drone in sight during theflight.
- The presence of people who might approach the pilot and co-pilot during the flight.
- The presence of animals that might interfere with the flight operations. If needed, a safety perimeter should be set up and/or changes should be made to the flight plan. Any significant finding should be reported on a logbook.

In situ weather assessment

The crew should check weather conditions on the site, especially with regard to wind speed, visibility and cloud height from the ground. This should be done by using specific instruments (e.g. handheld anemometer) and with a visual assessment if necessary. Indeed, wind speed can change from the point where it is measured (on the ground) to the altitude at which the aircraft flies, looking at the movement of trees around the area or at cloud speed can help in determining how strong is the wind. Usually, the manual of the platform contains information on the maximum wind speed at which it is advisable to fly the UAV (e.g. DJI, 2017; SenseFly Ltd, 2014).When flying at dawn or dusk; it is recommendable to double-check civil twilight hours. Notes about weather conditions should be as well reported on the flight logbook.4.3 Pre-flight controls before beginning the flight, the crew should check that all the necessary instruments are taken and working. To make this job more systematic, the use of a checklist is recommended. This should include:

· Check that the drone registration number is legible

· Check and that there is no external anomaly (e.g. in the propellers, transmitters, gimbal, etc.) (DJI, 2017; SenseFly Ltd, 2014)

· Check that the gimbal clamp and the lens caps have been removed

· Check that the SD card and the battery are in place

· Check that the batteries of the drone and of the computer are fully charged.

Flight

During the flight, the members of the crew take care of different tasks. The pilot is in charge of piloting the drone from takeoff until landing. Takeoff and landing require different operations in fixed-wing and multi-rotor platforms and whether the operation is manually or automatically conducted. However, there are some common steps to be followed in all the cases (e.g. DJI manual): first, the UAV and the remote controller must be turned on and connected; the Inertial Measurement Unit (IMU) and the compass must be calibrated; the GPS must be receiving signal from at least 6 satellites. The PIC should check that the takeoff could take place safely and announce loudly the beginning of the flight with a standard statement (e.g. "Take off"). When working with a multirotor, at first the UAV should be kept at eye-level altitude so that the PIC can check that the platform is stable and responding to commands. During the flight, the pilot should constantly check the behavior of the drone, as well as the remaining battery life and any event happening in the surroundings; if a co-pilot is present, the pilot should regularly communicate with him/her, to confirm that everything is in order and the flight can continue.

Before landing, the PIC should check that the landing area is safe and then announce clearly the landing with a standard statement (e.g. "Landing"). Finally, the PIC can proceed with the landing operations, which differ in case of automatic or manual mode.The co-pilot must maintain a visual line of sight with the drone during the flight to support the PIC, to ensure that even in the short moments when the PIC has to look away the drone is flying as expected. The co-pilot should immediately notify the PIC if the platform is not behaving normally or if a hazard arises. If necessary, the co-pilot should support the PIC in the takeoff and landing operations, ensuring that the site is safe. At the end of the flight, the PIC and the co-pilot need to remove the camera and the batteries from the drone.

Post-flight controls

After the flight, it recommendable to check the quality of the acquired images, so that, if the image quality is not good and if it is possible, the flight can be repeated. There are some programmes available to check image quality on the field (e.g. Post flight Terra 3D (SenseFly Ltd, 2014)).

Generic toolbox and other materials

There are a number of tools, which are helpful to have in the field, some of which are non-essential for successful UAV operation but can prove useful to secure against unplanned incidents. These items along with all UAV equipment and sensors should be listed on a check-list to ensure they are taken into the field. Items include:

a.Tools:

-Screwdrivers & Allen keys-Replacement screws & wingnuts

-Cable ties

-Duct-tape

b.Power:

-LiPo-safebags

-Powerbank mobile chargers

-Car power inverter / generator

c.Misc:

-Anemometer-First-aid kits-Two-way radios

-Fire extinguisher or blanket-High-vis vests (if necessary)

-Notepads & pens

-Head torch (if necessary)

-Food & water

-Safety tape (if necessary)

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