UAV and it’s Applications in Photogrammetry

CEN – 611 – Analytical and Digital Photogrammetry

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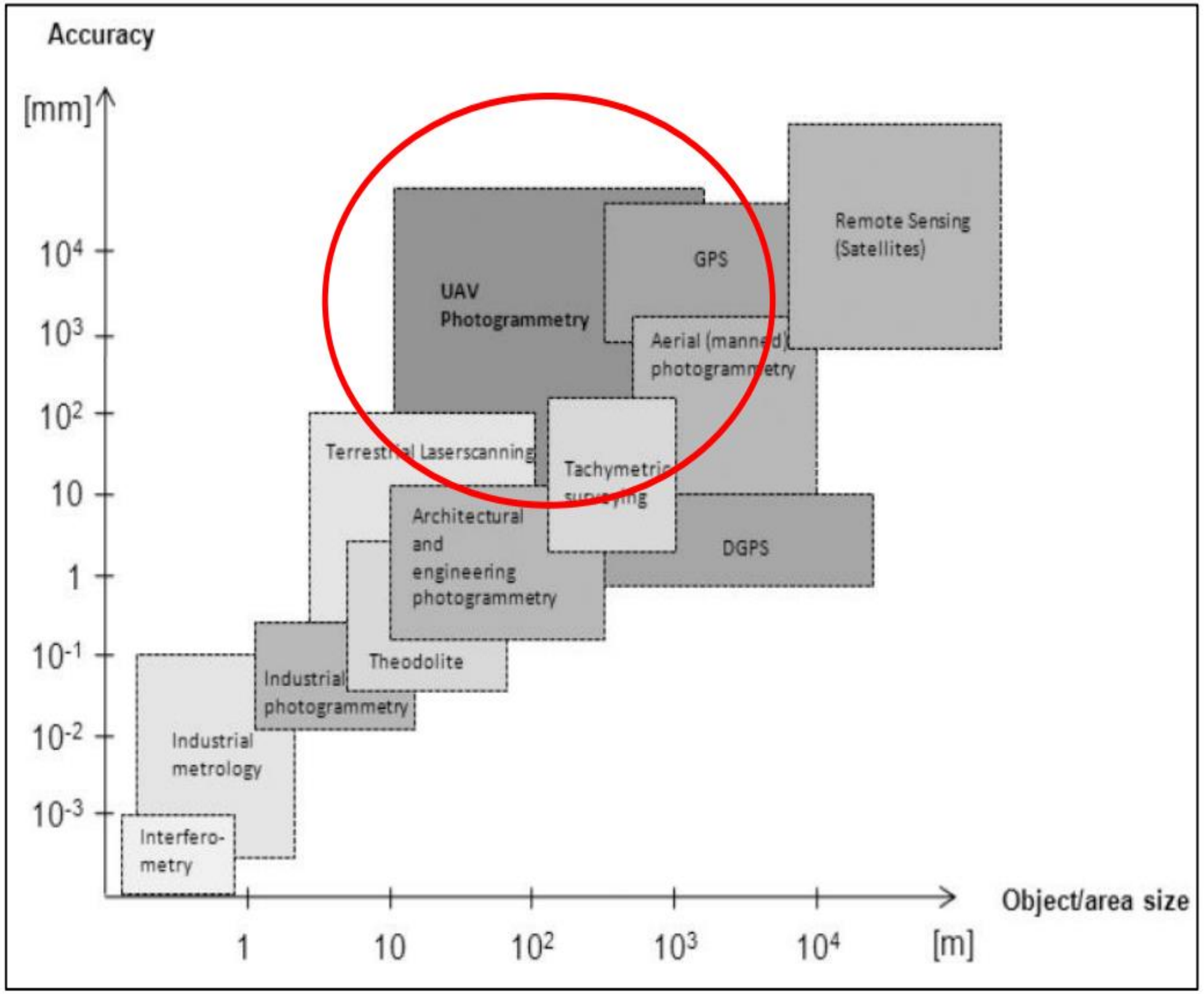
Introduction

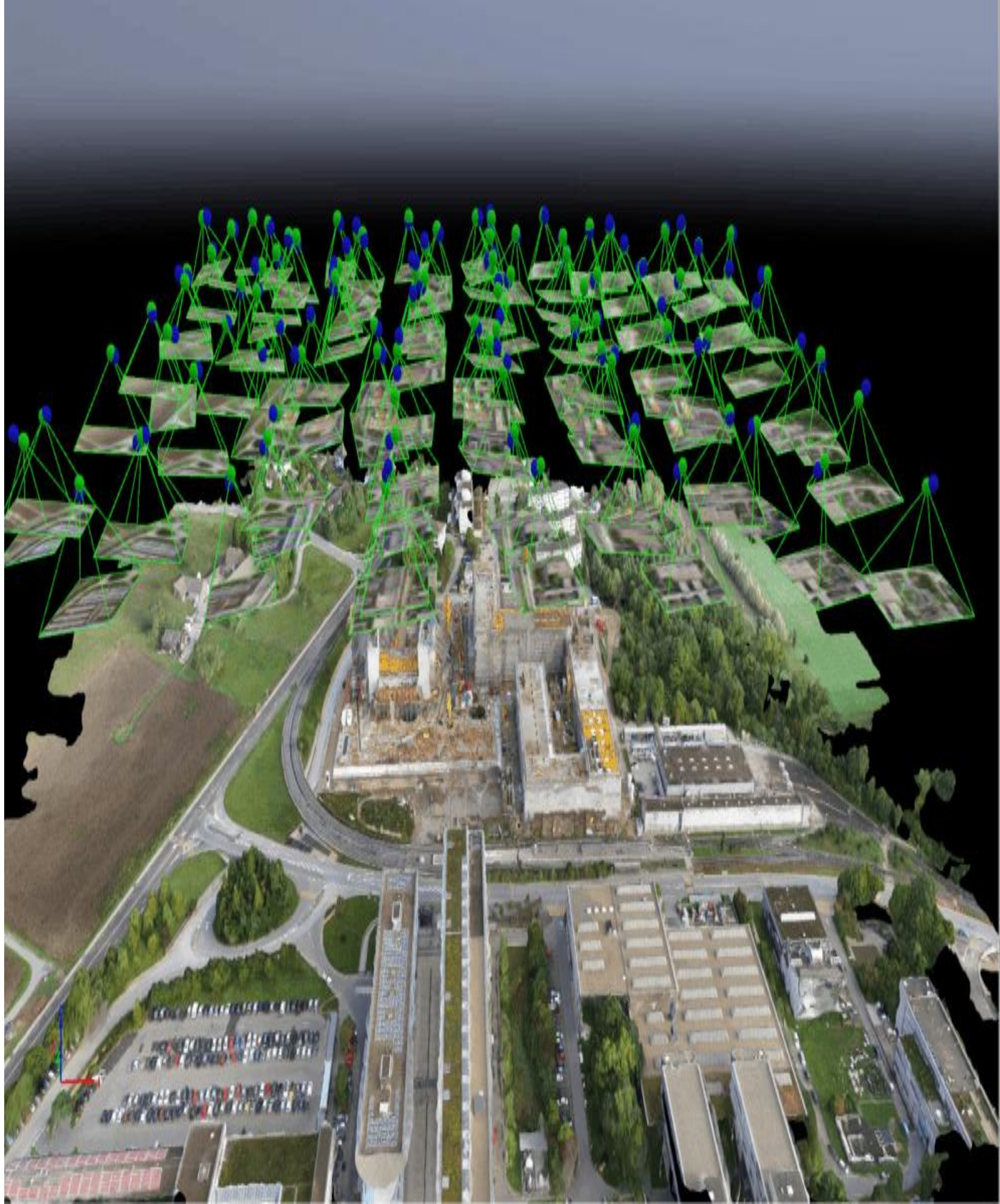
- Unmanned aerial photogrammetric survey uses unmanned aerial vehicles (UAVs) to take photos for use in photogrammetry, the science of making measurements from photographs.
- Instruments manufactured for UAVs could be mounted on unmanned flying platforms of various sizes and types, such as octocopters.
- These machines are suitable for the full geodetic survey of a study site by creating a point cloud of measurements of nearly homogenous quality and accuracy.
- These detailed point clouds (of various types of data) could be used in line with orthophotos etc. to obtain a complex data system representing the study site.
- Similarly to manned aerial surveys, UAVs are suitable to acquire three-dimensional digital models and orthophoto mosaics for a certain area.
- The biggest downside of this technology is that these UAVs, especially the smaller ones, could survey only a smaller area.

UAVs and Aerial Photogrammetry

- Unmanned Flight system technologies have seen exponential growth over the past decade, resulting in highly autonomous and accessible machines capable of a large range of functions.
- The figure on the right shows the relationship between object area size and accuracy using UAVs compared to other forms of photogrammetry in 2006.

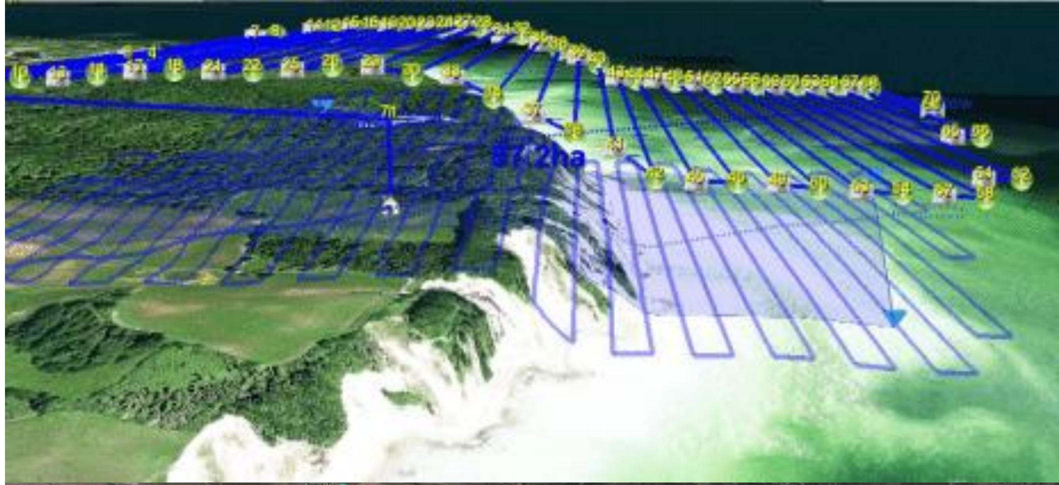


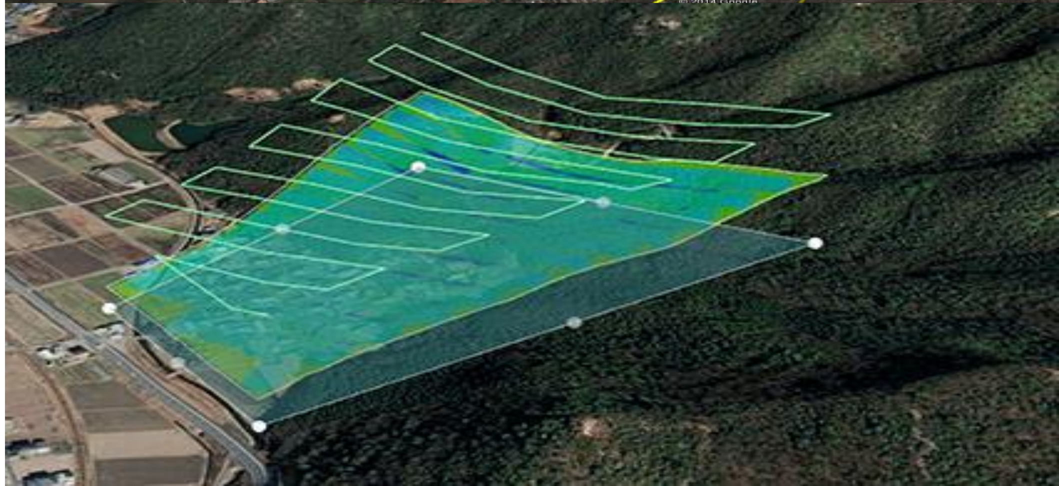
- This figure can be altered now due to the progress UAV technology has made over the past several years.
- Advancements in accuracy and flight navigation software have made the possibility of using UAV systems in photogrammetry, an economical and viable option for a number of applications.
- Real time positioning using GNSS receivers mounted to the body of a UAV increases the positioning accuracy of the camera station at the time an image is captured. This increases the overall accuracy of the geo-referenced model.



Flight Planning

- The mission (flight and data acquisition) is planned in the lab with dedicated software, starting from the area of interest (AOI), the required ground sample distance (GSD) or footprint, and knowing the intrinsic parameters of the mounted digital camera. Thus fixing the image scale and camera focal length, the flying height is derived.
- The camera perspective centers (‘waypoints‘) are computed fixing the longitudinal and transversal overlap of strips, while the presence of GNSS/INS onboard is usually exploited to guide the image acquisition.
- The take-off and landing operations are strictly related to the employed vehicle and characteristics, but normally controlled from ground by a pilot (e.g. with a remote controller).
- During flight, the platform is normally observed with a control station which shows real-time flight data such as position, speed, attitude and distances, GNSS observations, battery or fuel status, rotor speed, etc.
- Most of the systems allow then image data acquisition following the computed ‘waypoints’, while low-cost systems acquire images according to a scheduled interval.

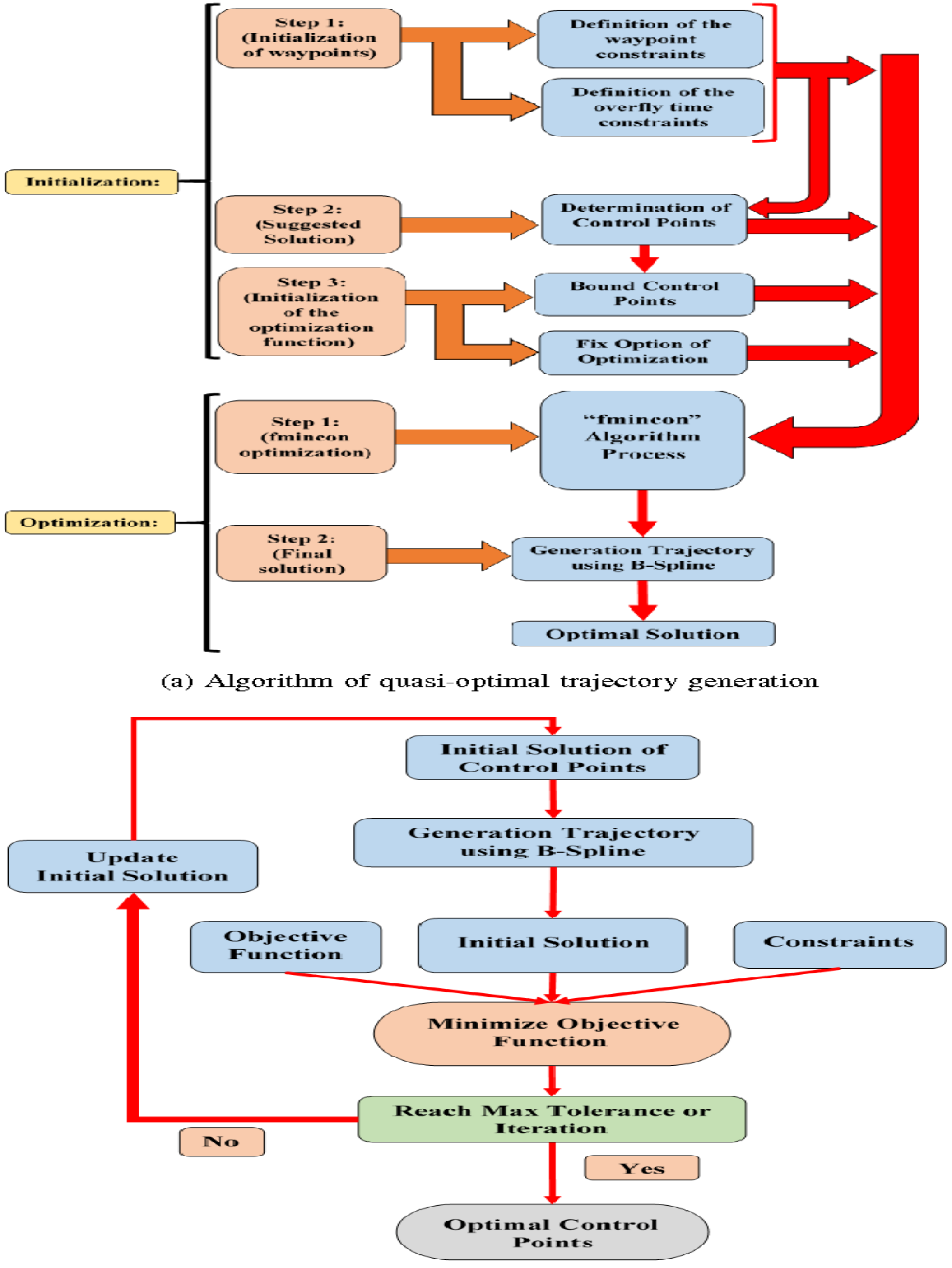




Flight Plan Optimization

The use of UAV systems in surveys has been proven to be cost effective and with the improvement of the GPS/INS integrated systems, the accuracies of the produced models will be highly beneficial in a variety of applications.

A simple program, WADE_flight2014, was developed to allow a user to select an area using a widely available mapping program such as Google Earth. Selecting a camera system to attach to the hexacopter, selecting the lens (fixed focal length is recommended for best results) and selecting a minimum flying height and timing of exposures. The program provides a number of options for flight plans as shown in the following figure allowing the user to select the appropriate option according to their specific restrains/ requirements.



(a) Algorithm of quasi-optimal trajectory generation

(b) "fmincon" algorithm process

Flight Optimization for UAV surveys

Inputs	
Camera (select)	Nikon D800
Lens focal Length (mm)	24
dx (m) user defined	300.00
dy (m) user defined	100.00
Photograph epochs (seconds)	2
Minimum flying height (m)	20

http://www.dpreview.com/products/

Optional Input	
New Camera name	
Sensor size x (mm)	
Sensor size y (mm)	
Megapixels	
Camera Resolution (x)	
Camera Resolution (y)	

Add Camera

New Lens focal length (mm)	

*Select new camera that has been added in the drop down list or select camera that is using the new lens. Input new lens focal length then press the "add lens"button. The lens will now be available to select in the drop down list

Add Lens

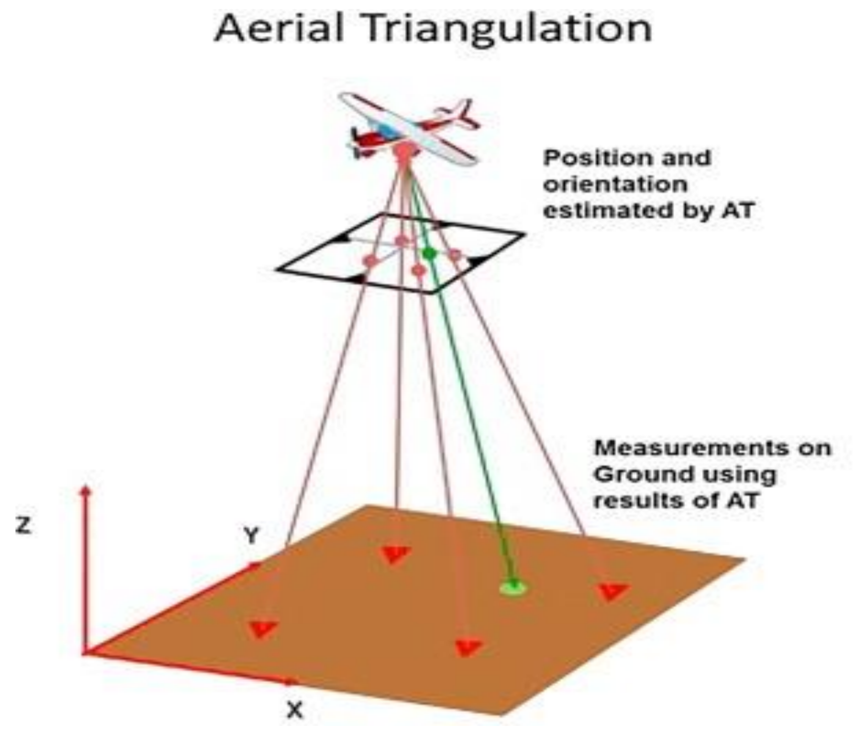
outputs

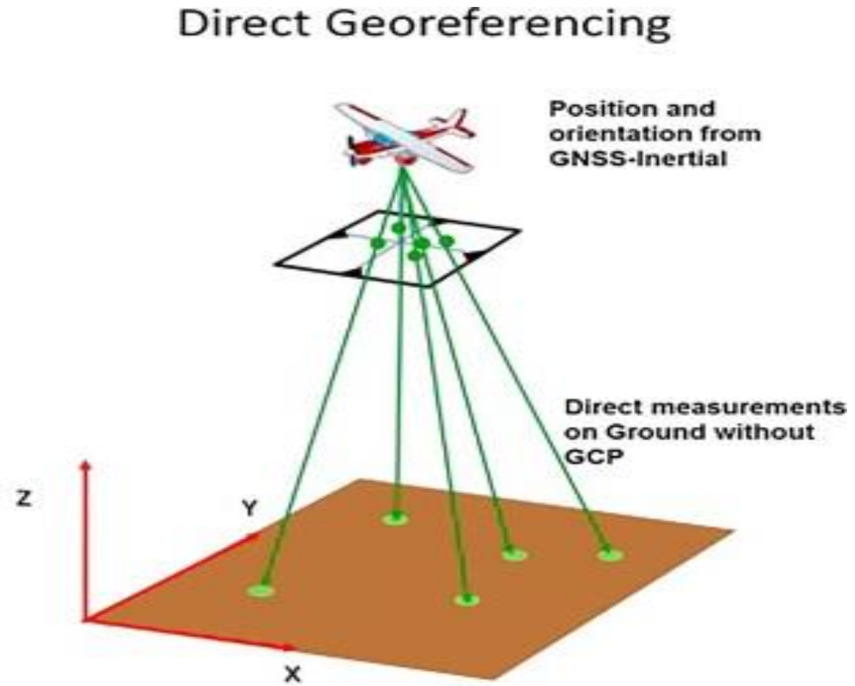
Area to survey (m^2)	30000

Flying height (m)	No. of photos	Pixel Size (mm)	σ planimetrc error (mm)	σ depth error (mm)	Flight speed (m/s)	Total flying time (minutes)	Minimum Shutter speed ($seconds^{-1}$)
20	813	4.1	2.1	7	3	27.08	732
25	500	5.1	2.6	8.7	3.8	16.45	745
30	383	6.2	3.1	10.4	4.5	12.50	726
35	290	7.2	3.6	12	5.3	9.43	736
40	219	8.2	4.1	13.7	6	7.29	732
45	173	9.2	4.6	15.4	6.8	5.51	739
50	125	10.2	5.1	17	7.5	4.17	735
55	119	11.3	5.7	19	8.3	3.77	735

Camera calibration and image triangulation

- Camera calibration and image orientation are two fundamental prerequisites for any metric reconstruction from images.
- In photogrammetric applications, the separation of both tasks in two different steps is preferred, also for UAV blocks without cross-strips.
- Indeed, both steps require different block geometries, which can be better optimized if they are treated in separated stages.
- On the other hand, in many applications where lower accuracy is required, calibration and orientation can be computed at the same time by solving a self-calibrating bundle adjustment.
- The camera calibration is generally performed in the lab although in-flight calibration are also performed.
- Camera calibration and image orientation tasks require the extraction of common features visible in as many images as possible.
- In aerial photogrammetry this task is accomplished today by exploiting automatic aerial triangulation (AAT) techniques.
- In close-range photogrammetry, the automation of this task is a more complex issue due to large (and often varying) image scale, convergent image geometry, irregular overlap, strong geometric and radiometric changes.

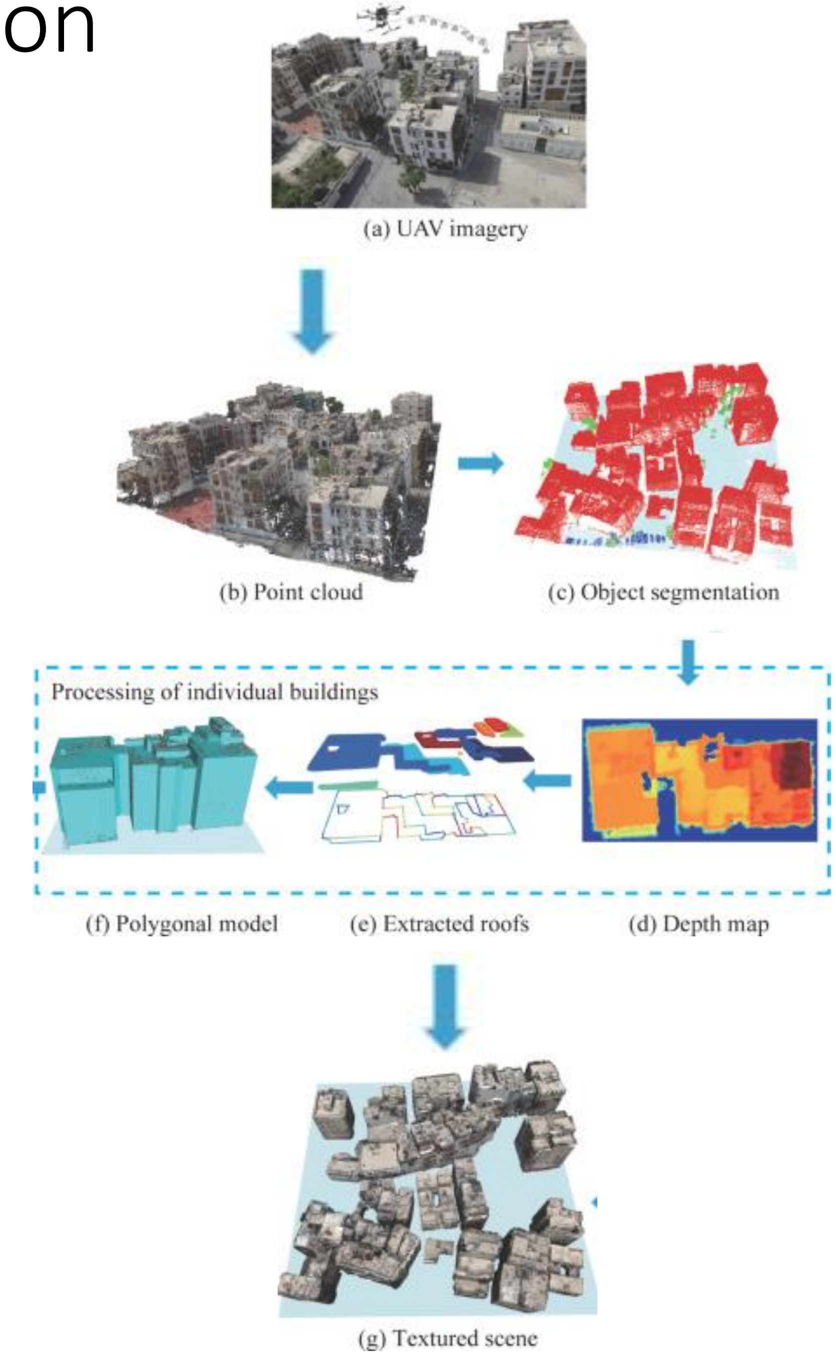




- In many cases, image blocks acquired by using UAV systems are more similar to close-range than aerial blocks.
- Consequently, standard AAT procedures do not work out properly.
- Procedure based on the manual identification of tie points by an expert operator or based on signalized coded markers are well assessed and used today in close-range applications.
- In recent years some procedures for the automated extraction of a consistent and redundant sets of tie points from marker less close-range (or UAV) images have been developed for photogrammetric applications.
- Some commercial solutions have also appeared on the market (e.g. PhotoModeler Scanner, Eos Inc; PhotoScan, Agisoft).
- The collected GNSS/INS data help for the automated tie point extraction and could theoretically allow the direct georeferencing of the captured images.
- But a bundle adjustment is generally computed, starting from the approximated exterior orientation (EO) parameters, to further refine the sought accurate camera poses and attitudes.
- In other applications with low metric quality requirements, e.g. for fast data acquisition and mapping during emergency response, the accuracy of direct GNSS/INS observation can be enough.
- But there are many surveying applications where the scene and location are not suitable (even partially) for direct geo-referencing techniques, like an object with prevalent vertical extension (e.g. a big building façade), or an environment where satellite visibility is limited or impossible at all (e.g. in downtowns, rainforest areas, etc.).
- In both cases the GNSS positioning can be hardly used even for autonomous flight modes as the signal is strongly degraded and thus the orientation phase can rely only on pure image-based.

Surface reconstruction and feature extraction

- Once a set of images has been oriented, the following steps in the 3D reconstruction and modeling process are surface measurement and feature extraction.
- Starting from the known exterior orientation and camera calibration parameters, a scene can be digitally reconstructed by means of automated dense image matching techniques or interactive methods for manmade features and vector information extraction.
- Interactive approaches deliver sparse point clouds which need structuring and editing in order to create accurate 3D data.
- Automated methods produce a dense point cloud describing the surface of the surveyed scene (DSM), which has to be interpolated, maybe simplified and finally textured for photo-realistic visualization.
- A powerful image matching algorithm should be able to extract dense 3D point clouds with a sufficient resolution to describe the object's surface and its discontinuities. Therefore the point density must be adaptively tuned to preserve edges and, possibly, avoid too many points in flat areas.
- At the same time, a correct matching result must be guaranteed also in regions with poor textures. The actual state-of-the-art encompasses the multi-image matching technique based on semi-global matching algorithms, patch-based methods or optimal flow algorithms.
- The last two methods have been implemented into open source packages named, respectively, PMVS and Micmac.
- Finally orthoimages can be produced and delivered for further processes, analyses and decisions.



3D Maps And Models

- To create 3D maps from aerial photogrammetry, the camera is mounted on the drone and is usually pointed vertically towards the ground.
- Using photogrammetry to create 3D models of monuments or statues, the camera is mounted horizontally on the UAV.
- Multiple overlapping photos (80 to 90% overlap) of the ground or model are taken as the UAV flies along an autonomous programmed flight path called a waypoint.
- To overlap photos of an object or land by 80 to 90% would be impossible to complete accurately by pilot navigation. It is essential to have a UAV which has waypoint navigation technology.

Drone Mapping And Lidar

- UAV lidar involves mounting a laser scanner on a UAV to measure the height of points in the landscape below the UAV. Lidar actually means (Light Detection And Ranging).
- Lidar scanners can capture hundreds of square kilometers in a single day.
- By measuring 10 to 80 points per square meter, a very detailed digital model of a landscape can be created.
- The accuracy of the measurements, allow the 3D models created using the lidar drone to be used in planning, design and decision making processes across various sectors.
- Lidar sensors can also pierce dense canopy and vegetation, making it possible to capture bare earth structure which satellites cannot see, as well as ground cover in enough detail to allow vegetation categorization and change monitoring.

Photogrammetry And Lidar Uses

Through the use UAV photogrammetry and lidar mapping, there is a large range of products, which can be extracted from the aerial imagery. These products include:

- DEM / DTM / DSM (surface models)
- Orthophoto's (geospatially corrected aerial images)
- 3D building models
- Contour maps
- Planimetric features (road edges, heights, signs, building footprints, etc)
- Volumetric surveys

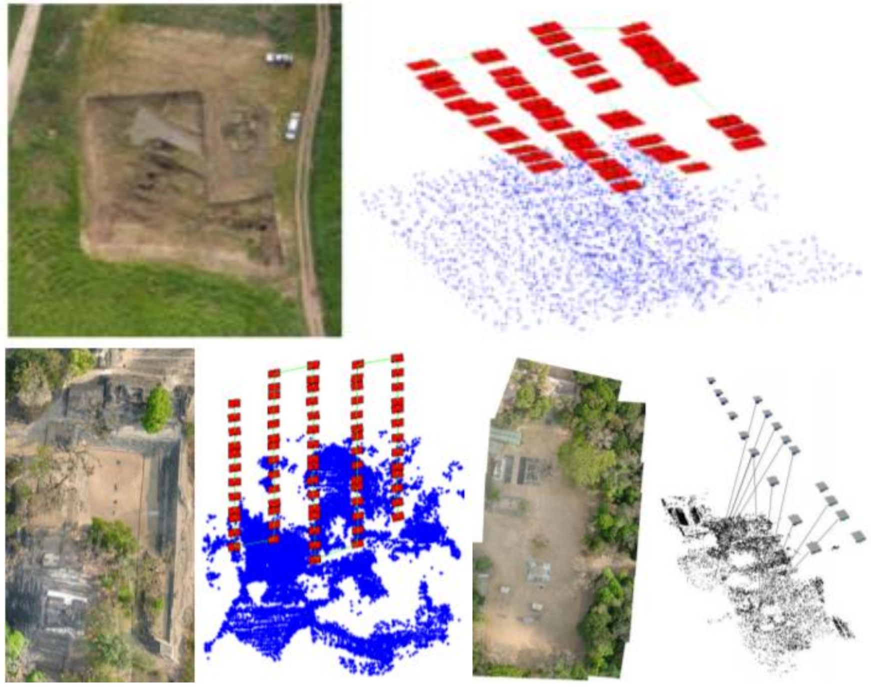
Here are some of the best uses of lidar and photogrammetry. All of these sectors benefit for having precision 3D images of their projects. They also benefit with increased efficiency and reduced costs than using traditional aircraft.

- Forestry management and planning
- Flood modelling
- Pollution modelling
- Mapping and cartography
- Urban planning
- Coastline management
- Transport planning
- Oil and gas exploration
- Quarries and minerals (Volumetrics and Exploration)
- Archaeology
- Cellular network planning

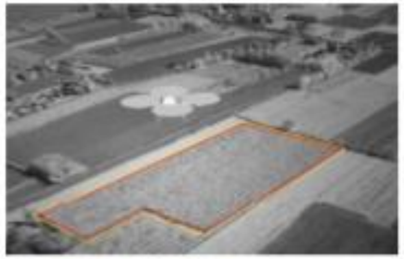
Applications in Photogrammetry

The typical domains were UAVs images and photogrammetrically derived 3D data or ortho images are generally employed include:

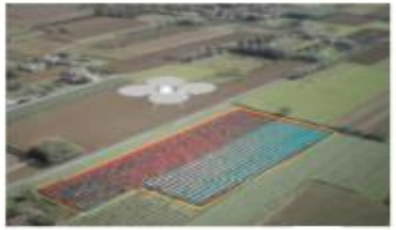
- forestry and agriculture: producers can take reliable decisions to save money and time (e.g. precision farming), get quick and accurate record of damages or identify potential problems in the field. Assessments of woodlots, fires surveillance, species identification, volume computation as well as silviculture can also be accurately performed.
- archaeology and cultural heritage: 3D documentation and mapping of sites and structures are easily achieved with a low-altitude image-based survey.
- environmental surveying: quick and cheap regular flights allow land and water monitoring at multiple epochs. Post-disaster response and mapping, excavation volume computation and natural resources documentations are also feasible.
- traffic monitoring: surveillance, travel time estimation, trajectories, lane occupancies and incidence response are the most required information.
- 3D reconstruction: unmanned aerial vehicles are a valuable source of image data for general 3D reconstruction purposes of man-made structures.



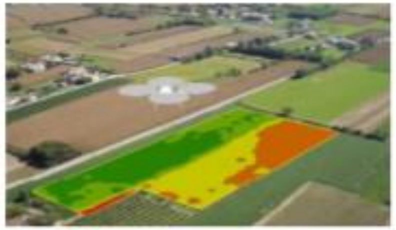
The studied wine yard area



seen in the NIR domain



with false colors



and the estimated NDVI index

Measuring Auxiliary data

- If a measurement is not recorded at the exact time an image is taken, the errors can be substantial as the plane or UAV is traveling at speed.
- If a UAV was flying at 5m/s and the time of GPS coordinate was 1/10th of a second after the image was taken, the camera station would be out by 0.5m.
- In a UAV where the camera is able to move around freely with the gimbal, any INS sensors would need to be located on the gimbal to determine the orientations at each point in time.

Ground/Object Coverage

- The benefit of using a GPS controlled UAV system is that the distance to the object can be somewhat defined in the flight plan and therefore this becomes a “known” factor in the similar triangle equations.
- An advantage of a full frame sensor is due to it being larger, the pixel size is increased. This enables more light to be captured by each pixel, allowing greater amount of light to be captured before the photodiode is oversaturated. Less noise is also present from neighboring pixels. These attributes conclude in a higher quality image at differing light and contrast situations which is helpful for the type of surveys that may be undertaken with a UAV.

Considerations of using an UAV

- The only way to improve height accuracy is to either decrease the flying height of the UAV (meaning more images need to be taken) or to reduce the overlap of images which may risk losing redundant data and a poor model.
- Due to this, where the lower focal length lens reduces the number of image required, the option to reduce the flying height such that the number of images required is the same-or similar-to that of the 35mm lens.
- Once the number of images is determined for varying target values, it is then dependent on how often ach image will be taken as to how fast or slow the UAV will fly.

- As long as the UAV flies below the calculated speed, the overlap between image pairs and flight lines will be at least the required amount (80%).
- Most flight systems on UAV hexacopters that have been investigated have the ability to define a flight speed between waypoints.
- No testing has been completed yet as to how accurate this speed is or indeed how wind affects the UAV speed.
- The low power consumption and the fast processing speed makes CMOS sensor useful for photogrammetric applications from a UAV.

- A correctly exposed image produces the best result and balance of natural light for the environment.
- The reason this is important when undertaking an aerial survey with a UAV is because there is movement involved.
- Fast shutter speeds are best to freeze a moving object to make it appear still and without blur.
- If the consideration is made that the UAV/camera is fixed in its space then the object/ground will be the moving target.
- Depending on how fast the target is moving, depends on how fast the shutter needs to close to avoid a blurry image.
- As a result of an effectively developed flight plan, the maximum speed of the UAV is known.
- To capture an image that is sharp, it is recommended that in the time it takes the image to be exposed, the object does not move more than 0.5-1 pixel (Gp).
- If the Gp and flight speed are known for a given target, focal length and camera, then shutter speed can be determined by

$$Shutter_{speed}{}^{-1} = \frac{\frac{\frac{1}{2}Gp}{1000}}{flight\ speed\ (ms^{-1})}$$

- This gives the shutter speed so that the UAV has only moved 0.5 pixel by the time the image has been exposed.
- This can be modified to half the value if the UAV is allowed to move 1 pixel during exposure time.

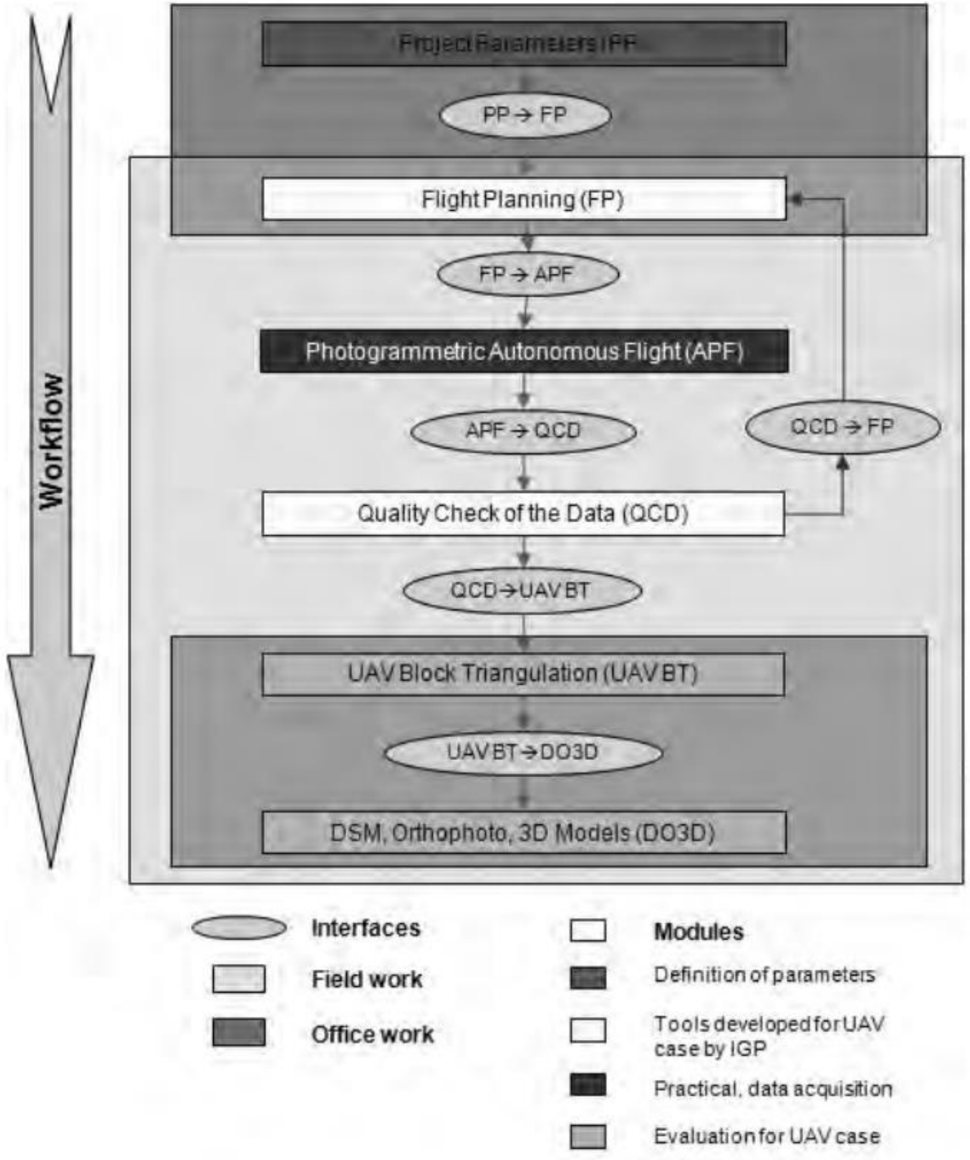
- When selecting the best aperture for UAV photogrammetry it can be more complex than setting the f-stop to f/32 or f/16 however.
- Due to the nature of the setting and the restriction of light, the image still needs to be correctly exposed to give a quality image and pixel value.
- A direct relationship lies between the aperture setting and the camera’s shutter speed.
- When the light enters the lens through the aperture opening, the shutter needs to stay open long enough to allow sufficient light through to the image sensor.
- When a smaller opening is set (i.e. f/22) less light is allowed through the lens and as a result the shutter must stay open longer to allow the sensor to be exposed.
- When the aperture number is set to a large opening (i.e. f/2.8), the shutter must close quickly as the excess light entering the lens can overexpose the image resulting in a white scene.
- It is important to understand these relationships as due to the moving nature of UAV photogrammetry and minimum shutter speeds, certain aperture settings may not be possible which could affect the depth of field for the images.

- ISO setting can be manipulated to create a balance between aperture and shutter speed and maximize the depth of field while still maintaining the minimum required shutter speed during a UAV photogrammetric survey.
- Understanding the three principals of exposure will inevitably allow the photogrammetrist to manipulate the camera settings in order to produce the best exposures for the lighting available.
- New technologies and cameras are finding a balance between the principals of exposure and automating the process substantially which is making it easier to obtain accurate and balanced images for use in many applications including photogrammetry.
- It is important that each of the settings allows for the scene to be captured with enough detail to permit the 3D models and orthomosaic photos to be useable and detailed.
- The UAV flight planning program WADE_flight2014 assists in determining the shutter speed however the aperture and ISO settings cannot be calculated using mathematical procedures as the amount of light in the environment will vary from survey to survey and therefore they must be adjusted to suit

Workflow of UAV application

The main modules of the workflow are as follows:

- Project parameters (PP)
- Flight planning (FP) o Autonomous photogrammetric flight (APF)
- Quality check of the data (QCD)
- UAV Block Triangulation (UAV BT)
- DSM, Orthophoto, 3D Model (DO3D)



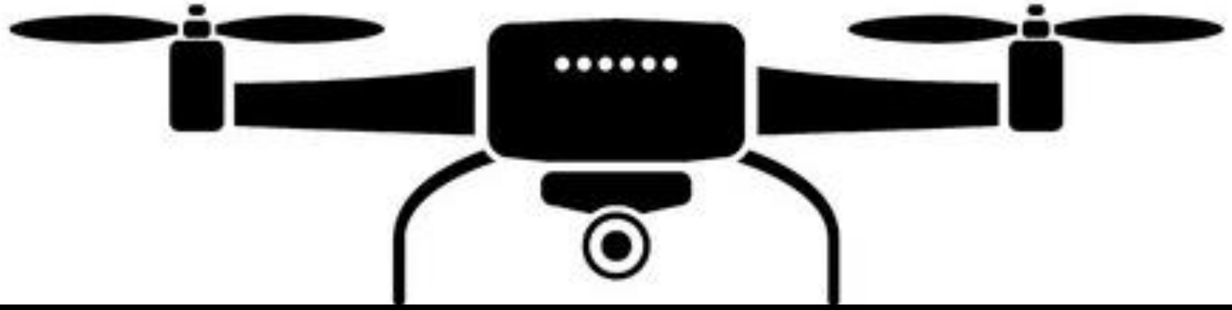
Modular Workflow for processing of UAV data showing the main functionalities

Pros

The machinery could be transported to the study site by car, thus transportation costs are low.
The deployment of the machinery is flexible.
It can operate and produce measurements in cloudy conditions.
The maintenance, storage and running costs of unmanned platforms are cheaper than the same expenses of conventional aircraft.
Moreover, the smaller high quality unmanned platforms are more efficient, productive and more durable than the conventional unmanned aircraft which could amortize quickly.

Cons

Smaller UAVs are only able to survey smaller areas.
The payload of the flying platforms is quite limited.
The legal procedures are more complicated and lengthy than the ones for manned aerial vehicles (e.g. airplanes, kites).
Reliable flying platforms of good quality are very expensive.



Thank You