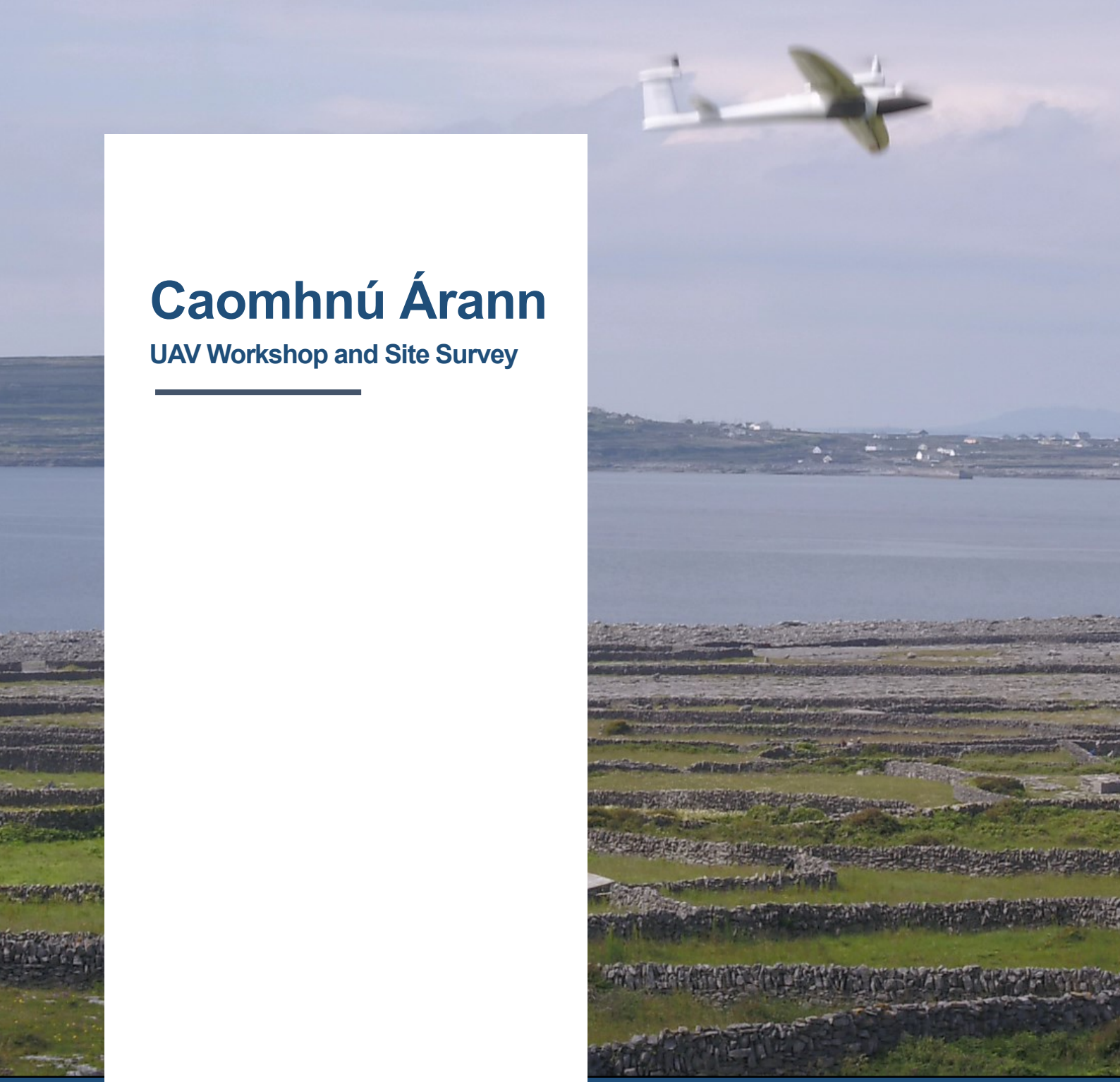


Caomhnú Árann

UAV Workshop and Site Survey

OCTOBER 2019

FINAL

Geo erospace

GEOSPATIAL AEROSPACE DATA COMPANY

Contents

1. Glossary

BVLOS Beyond Visual Line of Sight. Drones in the future will be allowed to be operated beyond visual line of sight

DSM Digital Surface Model. A 2.5D model of the ground below including topography, buildings, infrastructure, trees, and vegetation etc.

DTM Digital Terrain Model. A 2.5D model similar to a DSM but with all 'non' topographic' or 'non-ground' features such as buildings, trees, significant vegetation – essentially the 'bare earth' model

GSD Ground Sampling Distance. A measure used to define a camera's ability to resolve detail on the ground below e.g. 5cm GSD means the camera is able to resolve objects on the ground that are 5cm*5cm in dimension

GS Ground station. This is the control unit on the ground used by the drone operator to control/monitor the drone

Hybrid UAV. Drone capable of taking off and landing using vertical take-off and landing system but able to transition into conventional fixed wing flight after take-off

LOS Line of Sight. Drones are currently required here in Ireland to be operated within Line of sight which is defined as within 300m horizontally and < 120m vertically of operator

Multispectral Sensor. Sensor comprising a number of spectral bands e.g. green, red and infrared – enabling improved differentiation of vegetation and crops.

NDVI Normalised Distribution Vegetation Index. A ratio of a visible and infrared bands e.g. Green, Red and Infrared to accentuate 'red edge' response of crops and plants in near infrared and so better highlight vegetation

PPK Post Processing kinematic. A technique that enables GPS timing data to be record both on the drone and nearby on the ground (usually where operator is located). Post processing enable these two data streams to be fused and post-corrected resulting in centimetre level positioning of the UAV's flight path

UAV Unmanned Aerial Vehicle. This is the actual flying robotic platform

UAS Unmanned Aircraft Systems. Comprises the UAV, GS and Communication link between the two

VTOL Vertical take-off and Landing. A drone that is operated like a helicopter.

2. Introduction

This report discusses various approaches to dealing with data collection, processing and analysis when carrying out UAV surveys with specific reference to the Aran Islands. Following a workshop and subsequent site visits to the Aran Islands, the team at GeoAerospace have compiled this report to provide Caomhnú Árann with detailed information on the potential to integrate UAV surveys into their existing workflows.

The report addresses various topics including hardware, software, data acquisition, data processing and analysis, data quality aspects as well as the regulation and training required around the operation of UAV's in Ireland.

As part of this work, a workshop was held at the GeoAerospace offices in Maynooth in May 2019 and two UAV surveys were carried out on Inish Oirr and Inish Mhor during June and July 2019.

3. Workshop Topics

This section sets out the topics discussed during the workshop and responds to the original tender i.e. how to collect, manage, process and analyse UAV data in the context of the farm plan work on the Aran Islands. On larger, county/nationwide surveys, it may be more cost effective to carry out the work using satellite or aircraft surveys, however for the purposes of this project, UAV's are considered the most suitable data collection tool.

The topics discussed below include:

1. Hardware (UAV's)
2. Computer Hardware & GIS software
3. Geospatial data products (captured using UAV)
4. Regulation and legislation
5. Computing requirements

4. Hardware (UAV's)

Having consideration for a combination of factors, not least, Irish Aviation Authority (IAA) regulations, current technology limitations and budget constraints, we have set out a list of UAVs we feel are most appropriate for the work being carried out by Caomhnú Árann. The UAV listed below are suitable for commercial use and will on average, cover 20-25ha per 20-minute flight and are all capable of producing an orthomosaic of <5cm ground sampling distance (GSD). In comparison, the existing ortho imagery of the Aran Islands which was captured by light aircraft was 25cm GSD. Any UAV/drone data should be of higher resolution due to the lower operating altitude (<400ft), however the trade-off is that UAV's can only cover small areas at present due to current regulations i.e. operating in line of sight (LOS), typically300-500m radius.

GeoAerospace would recommend using a high resolution RGB drone and if budget allows, we would recommend the use of a multispectral sensor which can aid in improved classification & mapping of vegetation and plant species. Any RGB drone purchased should aim to provide a resolution of 5cm GSD or less in order to generate high resolution orthomosaics.

UAV/Drone	Sensor Included	Estimated Cost
DJI Mavic 2 Pro	RGB included	€1,500
DJI Phantom 4	RGB included	€1,700
DJI Mavic Enterprise	RGB & Thermal included	€2,900

DJI Inspire 2	RGB included	€6,000
	Multispectral excluded	€13,000
Quantum Systems Trinity F9	RGB included	€17,000

***Table 1**: UAV options*

5. Computer Hardware & GIS Software

There are numerous methods for handling and processing data, however for the purposes of managing UAV data, we have provided information on three potential solutions:

1. Low-cost, reasonable performance computer workstations for data processing and handling using open source QGIS – using hardware options discussed in **Section 8** below.
2. 'Pay as you go' data processing i.e. only paying for photogrammetry software on a rolling/monthly basis (as and when needed).
3. Outsource the work to a survey/data processing company.

For the pay as you go service, we would recommend the purchase of a cloud computing service such as Drone Deploy or Pix4D. These allow for *ad-hoc* use (i.e. monthly) and don't require processing power as the data is processed in the cloud. The primary requirement is good broadband speeds for uploading and viewing data. Much of the data processing is automated so it allows users with little GIS background, to produce useful data outputs such as those required on the Aran Islands i.e. high resolution orthomosaics. There is also free open source data processing available via Open Drone Map, although it should be noted that this requires a level of technical software competency, but it is a free yet powerful tool.

Cloud Processing Software	Estimated Cost (monthly)	Estimated Cost (yearly)
Pix4D	€260	€3,990
Drone Deploy	$449	$3,588
Open Drone Map (Open Source)	NA	NA

***Table 2**: Software Options*

All UAV data can be processed using the above commercially available cloud-based software where each of the digital outputs (orthomosaics/DSM's/NDVI's etc.) can subsequently be viewed and analysed within standard GIS software packages such as ArcGIS/QGIS etc.

During the processing stage, UAV data can be georeferenced in three ways:

1. Shape files or Google Earth (approx. 1m accuracy) etc.
2. Insert GCPs and use real time kinematic (RTK) GPS to record at 10cm level
3. Utilise onboard PPK or RTK from a UAV such as a Quantum Systems Trinity or DJI Phantom 4 RTK. Once the orthomosaic has been georeferenced and output as a GeoTif, it can be viewed with farm plan shape files in ArcGIS or QGIS or whatever mapping software is currently being used.

6. Geospatial data products (captured using UAV)

RGB is the default imagery for producing high resolution orthomosaics, however Caomhnú Árann should consider the low-cost Sequioa multispectral or in time, the more expensive Micasense Altum. GeoAerospace have demonstrated the capabilities of various RGB sensors and the Micasense sensor during the on-site surveys and the outputs can be found listed in **Tables 3 and 4** below.

Following on from a UAV survey, the basic data products should include orthomosaics (ideally georeferenced at 1m or better), Digital Surface Model (DSM) and/or Digital Terrain Models (DTM) but these can vary in Z accuracy depending on whether ground control points (GCPs) or post-processing kinematic (PPK) has been carried out.

For improved species classification, Vegetation Index maps such as NDVI's can also be generated from some RGB cameras but better results are generated from specific multispectral sensors such as the Sequoia and Altum referenced above. In addition, thermal imagery could be utilised for drainage analysis across land parcels on the island and these have also been listed in **Table 3** below.

7. Regulation and legislation

Drone training and licensing is not a legal requirement, however all operators must comply with the Irish Aviation Authority Small Unmanned Aircraft (Drones) and Rockets Order (SI 563 of 2015) which sets out what the legislation allows.

In summary, if operating within a license i.e. Specific Operating Permission (SOP) then the operator must operate within certain limitations which include, but are not limited to the following:

- All drones over 1kg must be registered with IAA
- No flights within Controlled/Restricted/Military Airspace without permission from Air Traffic Control
- No flights within 5km of airports
- Line of sight operations (LOS) only i.e. within 300m of the operator
- Maximum height of 400ft or 50ft in Controlled Airspace
- No closer than 30m to any person, vessel, vehicle or structure (not under your control)

For the purposes of working on the Aran Islands, it is recommended that any operator obtains an SOP so that they can operate outside the above basic limits. As set out by the IAA, the requirements when operating on the Aran Islands are as follows:

"During aerodromes hours of operation, small unmanned aircraft and drone pilots/operators are required to contact the aerodrome operator for permission to fly when flying within 5km of the aerodrome".

Source: Irish Aviation Authority (IAA) IAIP http://iaip.iaa.ie/iaip/IAIP_Frame_CD.htm

Contact details for operating on the Aran Islands:

- Phone: +353 91 593034
- Email: info@aerarannislands.ie / http://www.aerarannislands.ie

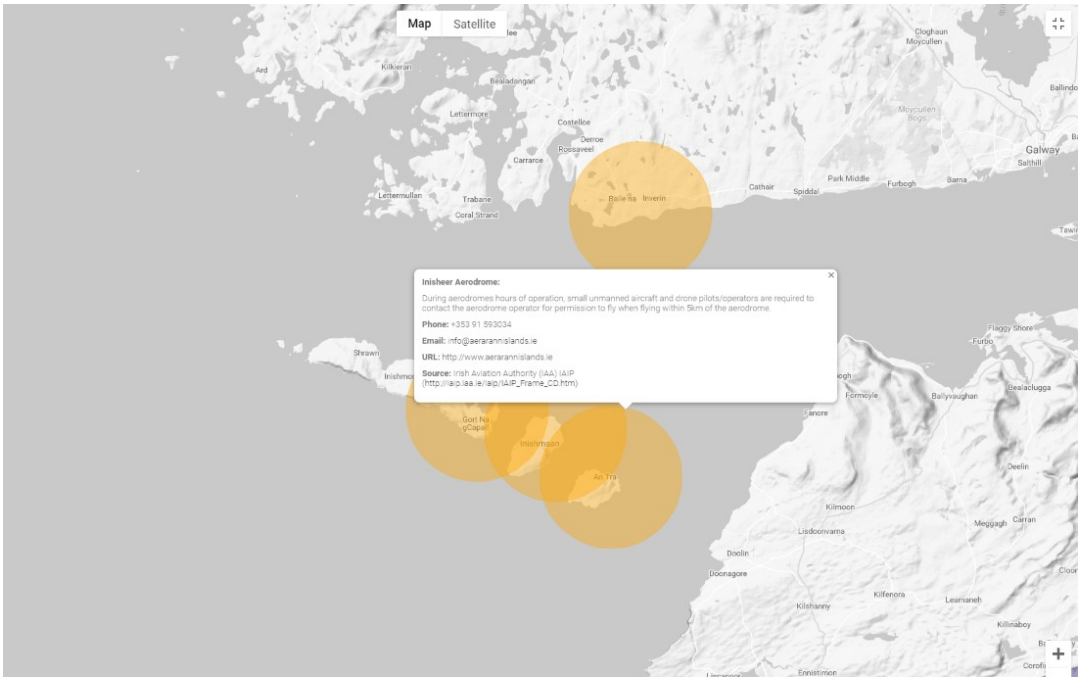


Figure 1: *Airspace map showing Aran Islands*

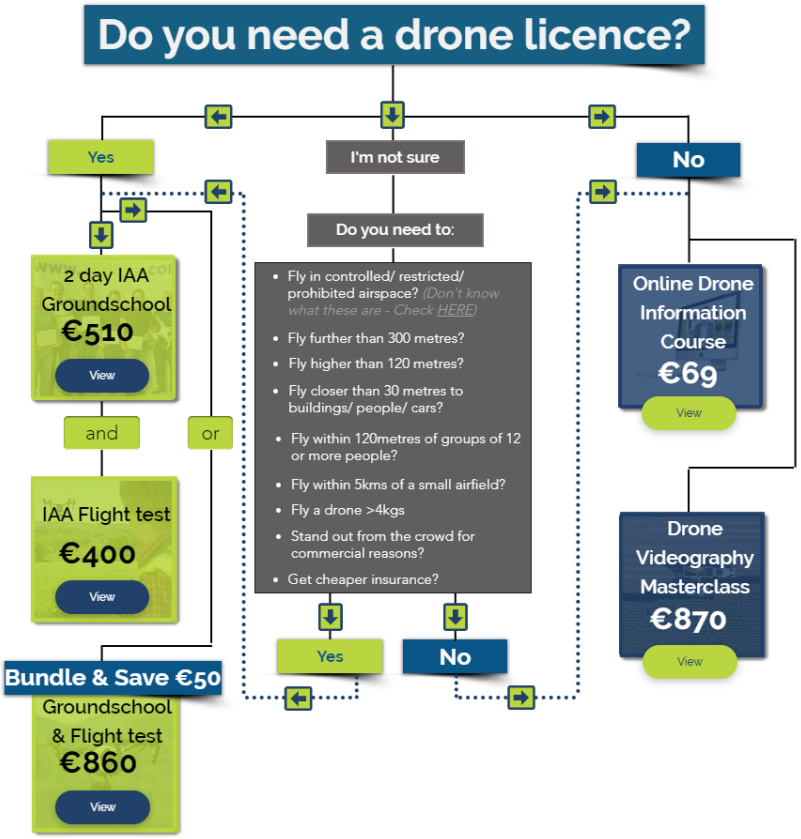


Figure 2*: A guide to training and costs associated with obtaining a UAV license (Source: FlyRyte)*

Recommended IAA registered training schools in Ireland include Safe Drone and FlyRyte. Both run two-day training courses around the country which cover the topics listed below in

greater detail. Once the training course is run, a flight test takes place and upon passing both, an Operations Manual is submitted to the IAA and the operator is granted an SOP.

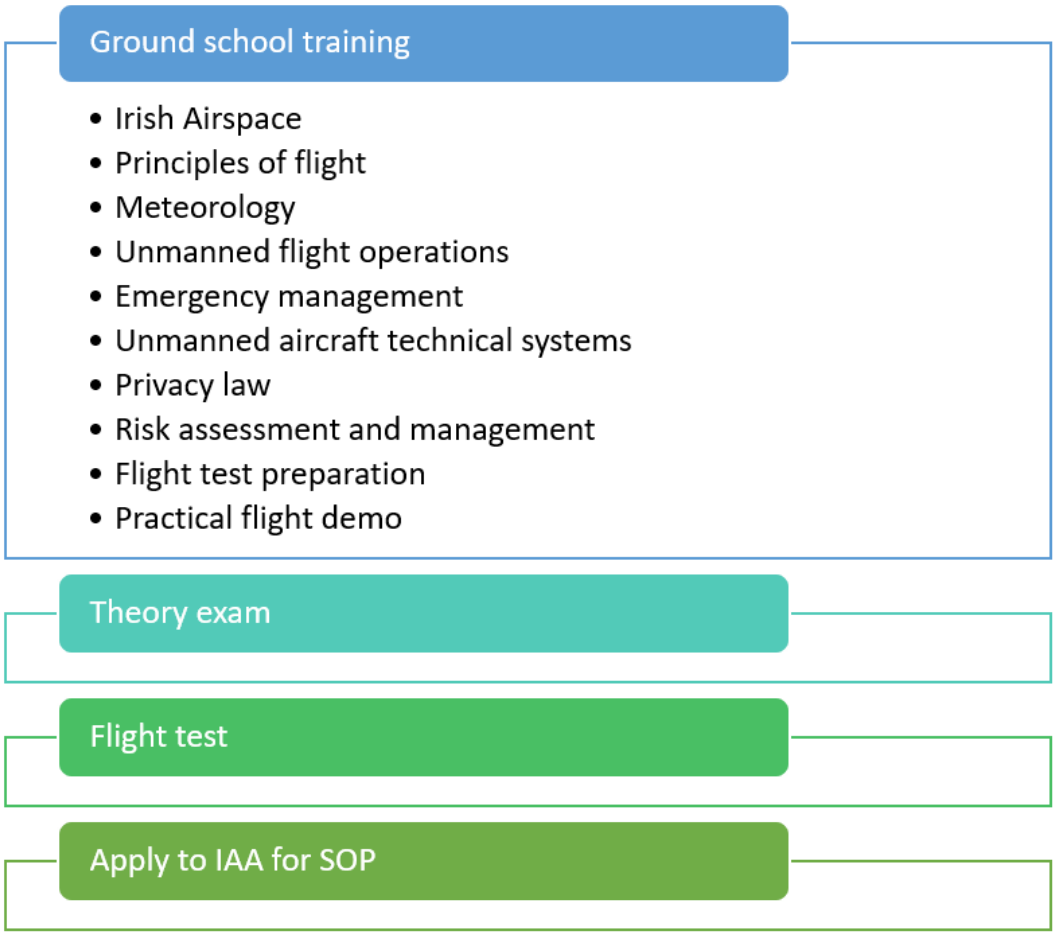


***Figure 3**: Typical Training School Curriculum*

8. Computing requirements

The below information relates to selecting a suitable computer/PC with enough processing power to handle processing optical imagery. We have listed the hardware requirements for both AgiSoft and Pix4D as these are the two software packages most commonly used when processing data locally on board your own PC/computer.

The following specification show the minimum and recommended hardware requirements for AgiSoft. The key components to any PC are RAM, central processing unit (CPU) and graphics processing unit (GPU).

RAM

In most cases the maximum project size that can be processed is limited by the amount of RAM available. Therefore, it is important to select the platform allowing to install required amount of RAM.

CPU

Complex geometry reconstruction algorithms need a lot of computational resources for processing. A high speed multi core CPU (3GHz+) is recommended.

GPU

Agisoft Metashape supports GPU acceleration for image matching and dense cloud generation steps, so high-end OpenCL or CUDA-compatible graphics card can speed up the processing.

Minimum:

- Windows 7, 8, 10, Server 2008, Server 2012, 64 bits (PC or Mac computers using Boot Camp).
- Any CPU (Intel i5/ i7/ Xeon recommended).
- Any GPU that is compatible with OpenGL 3.2. (integrated graphics cards from Intel HD 4000 or above).
- Small projects (under 100 images at 14 MP): 4 GB RAM, 10 GB HDD Free Space.
- Medium projects (between 100 and 500 images at 14 MP): 8 GB RAM, 20 GB HDD Free Space.
- Large projects (between 500 and 2000 images at 14 MP): 16 GB RAM, 40 GB HDD Free Space.
- Very Large projects (over 2000 images at 14 MP): 16 GB RAM, 80 GB HDD Free Space.

Recommended:

- Windows 7, 8, 10 64 bits.
- CPU quad-core or hexa-core Intel i7/Xeon.
- GeForce GPU compatible with OpenGL 3.2 and 2 GB RAM.
- Hard disk: SSD.
- Small projects (under 100 images at 14 MP): 8 GB RAM, 15 GB SSD Free Space.
- Medium projects (between 100 and 500 images at 14 MP): 16GB RAM, 30 GB SSD Free Space.
- Large projects (over 500 images at 14 MP): 32 GB RAM, 60 GB SSD Free Space.
- Very Large projects (over 2000 images at 14 MP): 64 GB RAM, 120 GB SSD Free Space.

If choosing software such as Pix4D to process the data, then the following specification show the basic, advanced and extreme configurations recommended.

Basic Configuration (up to 32 GB RAM)

- CPU: Quad-core Intel Core i7 CPU, Socket LGA 1150 or 1155
- Motherboard: Any LGA 1150 or 1155 model with 4 DDR3 slots and at least 1 PCI Express x16 slot
- RAM: DDR3-1600, 4 x 4 GB (16 GB total) or 4 x 8 GB (32 GB total)
- GPU: Nvidia GeForce GTX 980 or GeForce GTX 1080 (optional)

Advanced Configuration (up to 64 GB RAM)

- CPU: Octa-core or hexa-core Intel Core i7 CPU, Socket LGA 2011-v3 or 2011 (Broadwell-E, Haswell-E, Ivy Bridge-E or Sandy Bridge-E)

- Motherboard: Any LGA 2011-v3 or 2011 model with 8 DDR4 or DDR3 slots and at least 1 PCI Express x16 slot
- RAM: DDR4-2133 or DDR3-1600, 8 x 4 GB (32 GB total) or 8 x 8 GB (64 GB total)
- GPU: Nvidia GeForce GTX 980 Ti, GeForce GTX 1080 or GeForce TITAN X

Extreme Configuration (more than 64 GB RAM)

- For processing of extremely large data sets a dual socket Intel Xeon Workstation can be used.

9. Site Visit (Data Acquisition)

A sample area was surveyed on Inish Oirr (**Figure 5**) to demonstrate the capability of various drones and sensors and to show how to capture drone data in real world environments. The second, and larger area (approx. 700ha) was captured on Inish Mhor as part of the ongoing farm plan work and this is illustrated in **Figure 6** below.

***Figure 4**: Site Visit Photos*

Drones & sensors used to capture data during the site work:

- **RGB**: DJI Mavic Pro and Quantum Systems Trinity F9
- **Thermal**: DJI Mavic Pro Enterprise
- **Multispectral:** DJI Inspire 2 with Micasense Altium

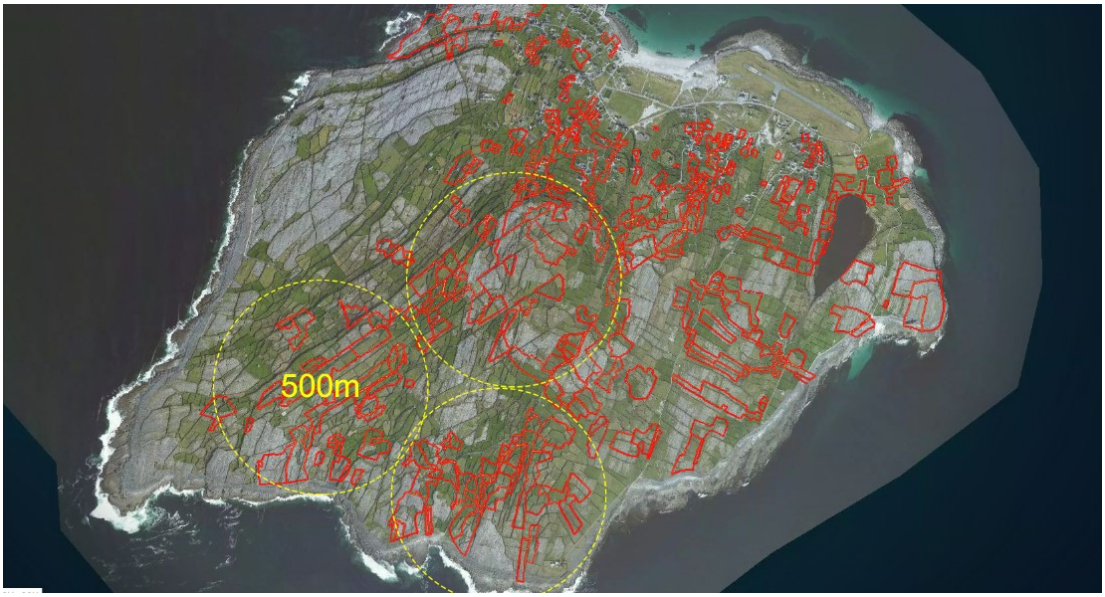


Figure 5: *Area surveyed on Inish Oirr (within circle marked with 500m) with multiple sensors*

As part of the workshop demonstration on the first day, the data acquisition was broken into two separate areas within a 500m radius on the south-west corner of Inish Oirr (**Figure 5**). A range of drones and sensors were flown, and small sample areas were mapped to show various capabilities and sensor quality. The results from that survey are listed in **Table 3** below.

For the second survey, a large area of Inish Mhor was surveyed with RGB sensors only for the purposes of mapping large parts of the island that were inaccessible or hard to reach on foot. Due to the size, the area was divided into nine x 500m zones (see **Figure 6** below). The outputs from that survey can be found in **Table 4** below.

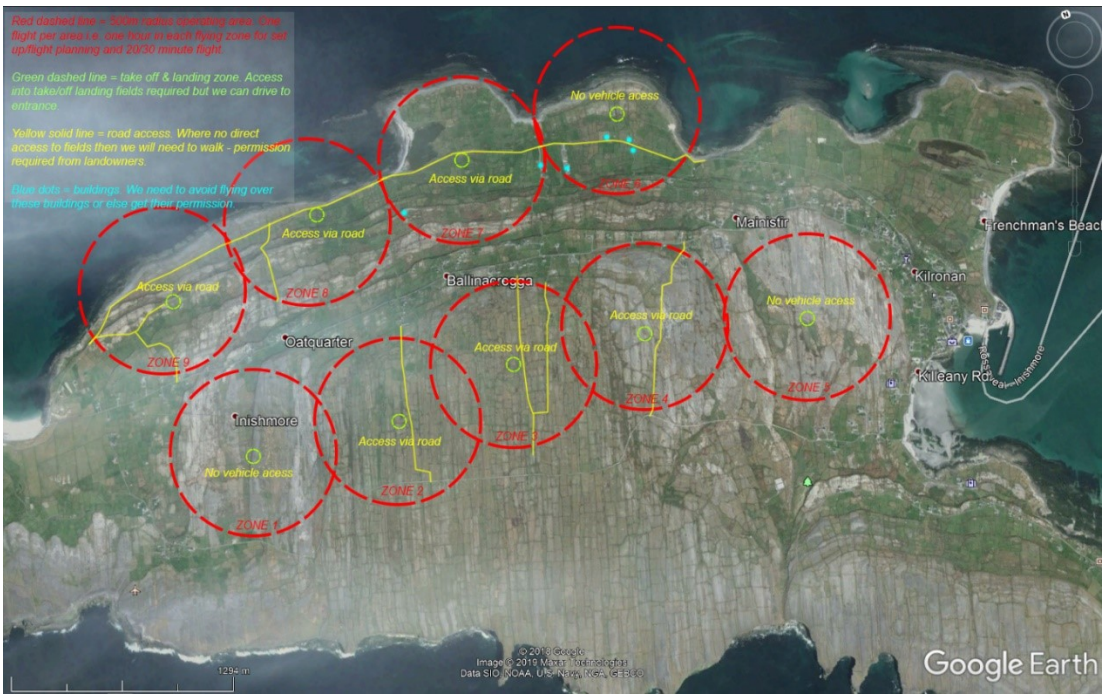


Figure 6*: Area Surveyed on Inish Mhor – approx. 700ha with RGB sensors*

Due to the number of regional airports and commercial/private aircraft operating in the area, the procedure for mapping on the Aran Islands is as follows:

1. Carry out risk assessment and flight plan at least one week in advance
2. Notify Aer Arran of planned time/date and location (altitude and area of coverage) at least a few days in advance
3. On the day, call Aer Arran before & after operating

To acquire the data on site, initial desk-based site planning was undertaken. Depending on the selected drone, there are a number of different mission planning applications available on the market. For the purposes of the survey flights, GeoAerospace used Map Pilot by Maps Made Easy and DJI GS Pro for creating the flight plans. This enables fully automated data collection. Once the drone/sensor, swath width, flying altitude, speed and area of interest are chosen, the flight plan app creates the mission and once on site this is uploaded and flown autonomously. **Figures 7 and 8** below show screengrabs from both apps.

***Figure 7**: Map Pilot app view during data acquisition*

With a standard consumer drone (e.g. DJI Mavic/DJI Inspire 2), it is possible to map up to 30 hectares on a single flight i.e. 1 battery/20 mins. The resulting data can then be processed using one of the cloud-based solutions discussed in **Section 5** above, in approximately 2hrs with good internet connection.

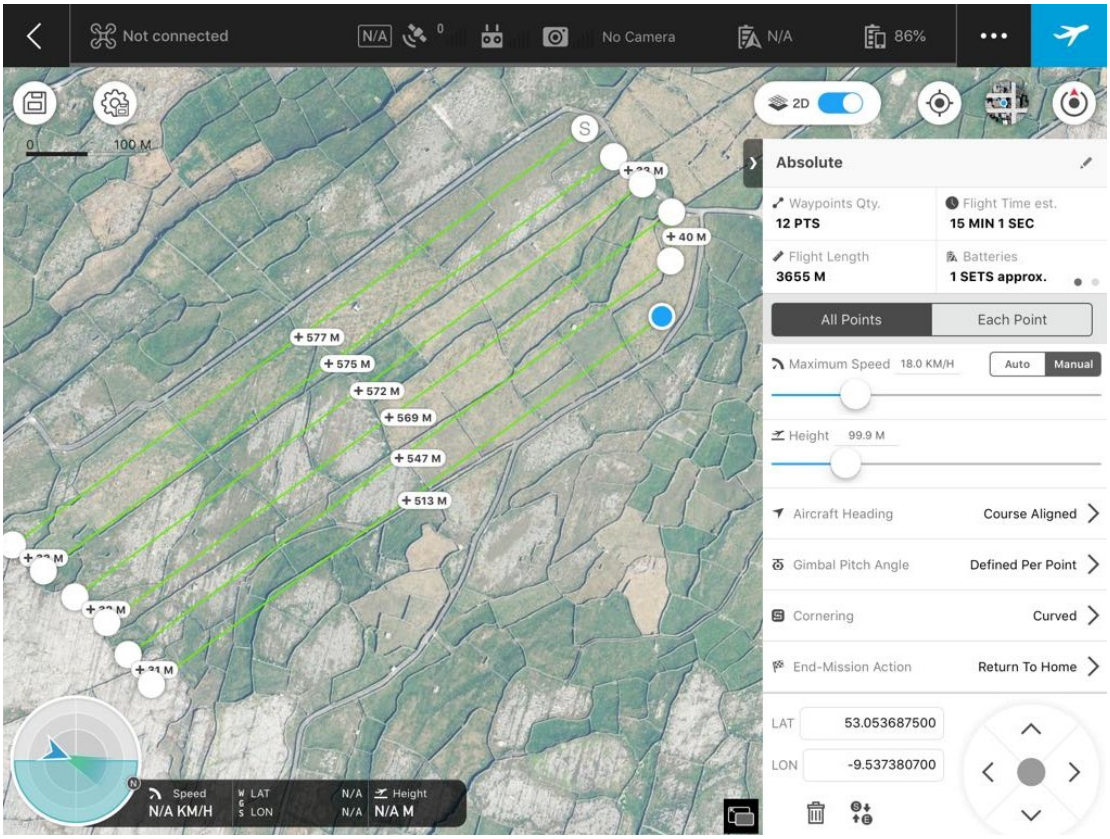


***Figure 8**: DJI GS Pro app view during data acquisition*

10. Survey Outputs

Table 3 below lists the outputs from each UAV survey with various sensors and levels of accuracy captured on Inish Oirr. The subsequent images illustrate some examples of the various outputs processed following the initial site visit/demonstration. **Table 4** lists the outputs from the surveys carried out on Inish Mhor.

Each output listed in **Table 3** is geospatially referenced and available for download and use.

INISH OIRR SURVEYS				
Site	**UAV**	**Sensor**	**Output**	**Accuracy**
Site 1	Quantum Systems Trinity UAV	RGB	Orthomosaic & Digital Surface Model	PPK
Site 1	DJI Mavic Pro UAV	RGB	Orthomosaic	GPS
Site 1	DJI Mavic Pro UAV	RGB	Orthomosaic	Recorded GCP's
Site1	DJI Mavic DUO UAV	RGB & Thermal	RGB Orthomosaic Thermal Orthomosaic	Recorded GCP's
Site 1	DJI Inspire 2 UAV	Multispectral & Near Infrared	Orthomosaic	Recorded GCP's
Site 2	DJI Mavic Pro UAV	RGB	Orthomosaic	GPS
Site 2	DJI Mavic Pro UAV	RGB	Orthomosaic	Recorded GCP's

Site 2	DJI Mavic Pro UAV	RGB	Digital Surface Model	Recorded GCP's

Table 3: *List of Outputs delivered from demo surveys on Inish Oirr*

INISH MHOR SURVEYS				
Site	**UAV**	**Sensor**	**Output**	**Accuracy**
Zone 1	Quantum Systems Trinity UAV	RGB	Orthomosaic	Recorded GCP's
Zone 2	DJI Inspire 2/Mavic Pro UAV's			
Zone 3	DJI Inspire 2/Mavic Pro UAV's			
Zone 4	DJI Inspire 2/Mavic Pro UAV's			
Zone 5	DJI Inspire 2/Mavic Pro UAV's			
Zone 6	DJI Inspire 2/Mavic Pro UAV's			
Zone 7	DJI Inspire 2/Mavic Pro UAV's			
Zone 8	DJI Inspire 2/Mavic Pro UAV's			
Zone 9	DJI Inspire 2/Mavic Pro UAV's			

Table 4*: List of Outputs delivered from demo surveys on Inish Mhor*

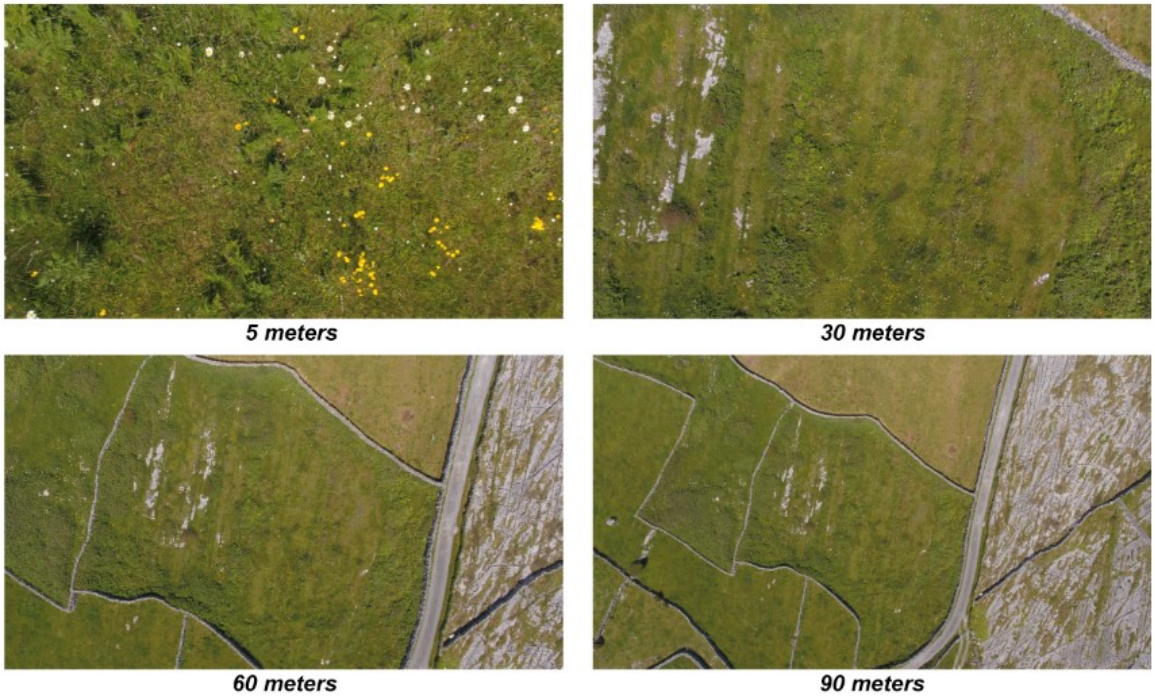
Image 1*: Site 2, Mavic Pro (RGB) tied down with GPS*

Image 2: *Site 1, Mavic Duo (thermal) tied down with recorded GCP's*

Image 3*: Site 1, Altum (Near Infrared), tied down with recorded GCP's*

In addition, a comparison of image quality from various heights from 5m to 100m was undertaken and the images can be found here. The comparison was carried out using an Inspire 2 UAV with Olympus 12mm lens and example outputs can be viewed in detail on the link above and can be seen on the image below.

For maximum area coverage during a survey, the maximum flying height is preferred i.e. 120m/400ft, however in the context of Aran Islands surveys a balance should be found which allows identification of plant species. As such, this may require a lower flying height resulting in less area coverage but a higher resolution map. Using the below images to review the various flying heights should aid in the decision-making process for determining the optimum flying height for species identification.



11. Conclusions

Following the workshop and subsequent on-site surveys and having discussed the specific project needs with the team at Caomhnú Árann, GeoAerospace consider that there are two suitable options for the collection of aerial data on the Aran Islands.

Option-1

The first option involves undertaking the survey work locally on the Aran Islands, utilising local farmers who are trained to operate UAV's and using off the shelf cloud computing software to process the data. The costs below are estimated, and additional costs will no doubt be required depending on the specifics of the work so figures are arbitrary and should be confirmed:

- Have local operators trained and licensed (€1,000/person)

- Purchase UAV's i.e. DJI Mavic's covering 20ha per 20 mins flight (€1,500/drone) or Quantum Trinity covering 100ha per 20 mins flight (€17,000)
- Insurance for DJI Mavic & public liability estimated at €1000/year
- Purchase monthly software licence (€260/month)

The primary advantage of the above option is that all work is done locally/'in-house', data can be collected as and when required and much of the data processing can be automated using cloud software such as Pix4D. In addition, the requirement for expensive PC hardware is negated by using a cloud solution. Disadvantages include the high costs of hardware (UAV's) i.e. replacing components every approx. 200 flights (2 years) and dealing with the complexities and inconsistencies that can arise when collecting data which is carried out by multiple operators.

Option-2

The second option is to outsource the work (both data acquisition and processing) to a specialist survey company and to host all the data on one centralised geospatial platform which is available to farmers to view as and when is needed. This has a number of advantages;

- Lower Costs:
    - No need to invest in drone, sensor and computing infrastructure
    - No need to invest in training, insurance and consumables
    - Only collect and process data when required
- Limited Shelf Life: This type of technology has a shelf life of 18months to 24 months so, upgrades may be required after 2 years
- Frequency of data acquisition: Generally frequent flying and processing is required to ensure operators and data-processors retain currency and keep up to date with best industry practice
- Liability and Risk: There is a certain amount of risk associated with operating drones
- Support & training: Avail of support since no mapping job is ever straight forward and a lot of expertise and skills are required from data capture, through to processing and final analysis

Recommendation is that the team at Caomhnú Árann would consider partnering with an Irish based geospatial technology company with expertise and capability in this area for even the first year of activity. This would allow the Caomhnú Árann team to concentrate on overall management of resources, planning location of surveys and exploiting the results of the mapping activities. The geospatial technology company should then provide the drones, standalone PC and cloud mapping resources as well as training and support.

After the first year, the Caomhnú Árann team would then be able to make an informed decision based on practical experience of managing this activity over the initial year.