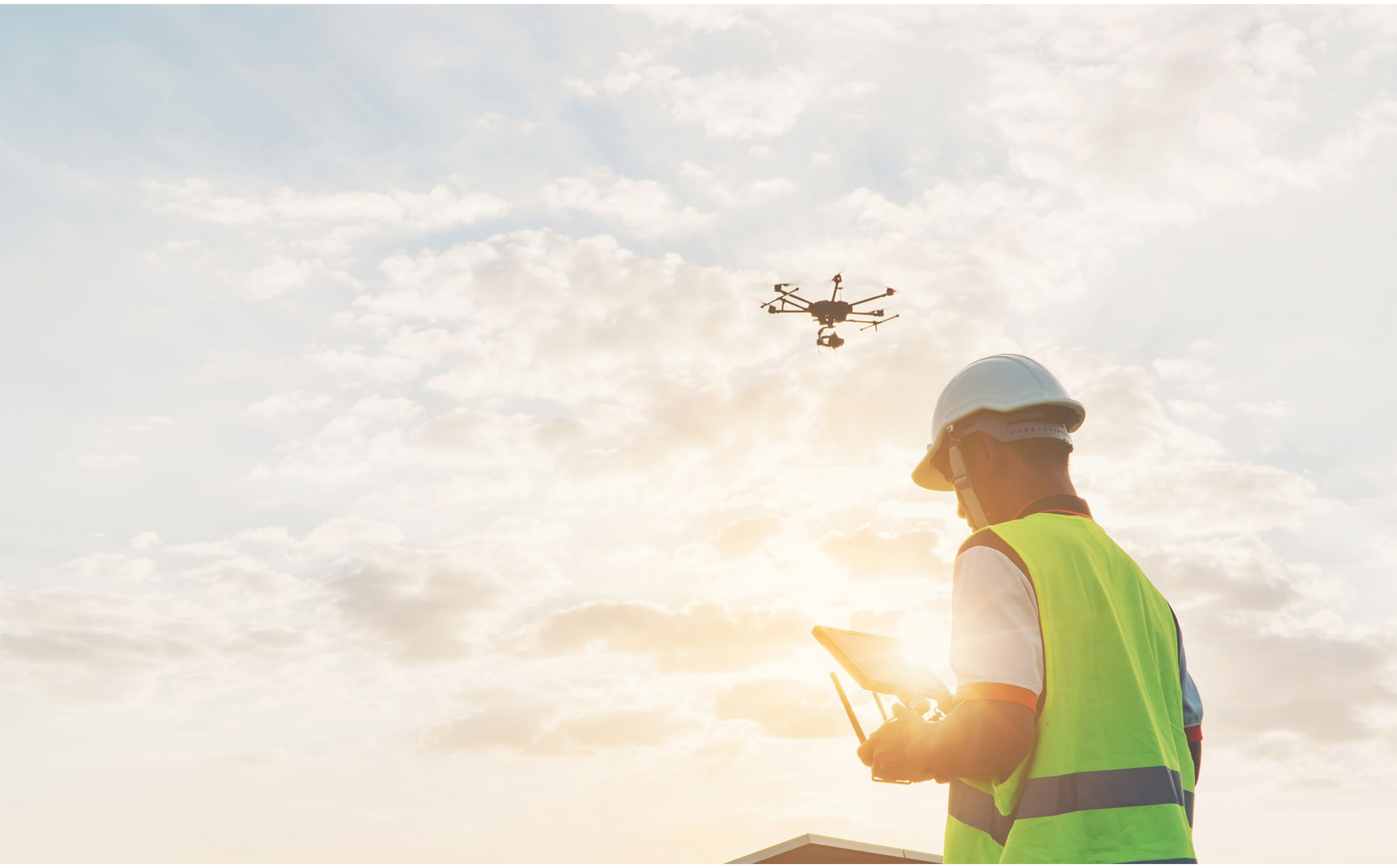
Co-funded by the Erasmus+ Programme of the European Union

MODULE 09

TRAINING PROGRAMME

LIDAR



Dirección General de Formación CONSEJERÍA DE ECONOMÍA, HACIENDA Y EMPLEO · DEX Desarrollo de Estrategias Exteriores · CAMPUS DES MÉTIERS ET DES QUALIFICATIONS D'EXCELLENCE Habitat, énergies renouvelables et éco-construction Occitanie · MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University · BZB Bildungszentren des Baugewerbes e.V. · fh Kufstein Tirol University of Applied Sciences

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1. Module Objectives

This module will introduce the learner to ***LiDAR*** and how this remote sensing technology may be used in conjunction with UAS to capture filed data. The ***key terminology*** with regards to LIDAR scanning is identified as is the primary methods as to how a LiDAR scan may be carried out. An ***illustrated example*** of the steps involved in successfully carrying out a ***LiDAR scan*** using a UAS is explained and how the resulting data may be processed. Finally, some examples of the many ***applications within the construction industry*** for which this technology may be used in conjunction with UAS are discussed.

2. Lidar Introduction

2.1 What is LIDAR?

LiDAR (light detection and ranging) is an active remote sensing method that utilises a laser or light to measure objects. In a LiDAR system, the distances (or ranges) to an object are measured through pulses of light that are emitted from a rapidly firing laser scanner. When a pulse of light hits a target, a portion of its photons are reflected back to the scanner where it can be measured and recorded. The LiDAR "***pulse***" refers to the emitted photons of light and those that are reflected back or return are referred to as the "***echo***" or "return". LiDAR scanners can be mounted on a number of different platforms for scanning operations including tripods or aircrafts (UAVs, planes etc) as illustrated in Figure1.

A LiDAR system measures the location of the scanner, the direction or angle of the emitted light and the time taken for the light to travel to the object and back. As the speed of light and scanner location is known, the recorded time from emission of light (pulse) to the reflected return (echo) may be used to calculate the 3d location (x,y,z coordinates) of the reflecting object using basic geometry. During a LiDAR scan, a laser may emit millions of times stamped light pulses recording from when and where they reflect producing an accurate 3D point cloud of the target object or area. Such data may then be used to develop digital models to estimate the 3D structure of the target object or area.

a b

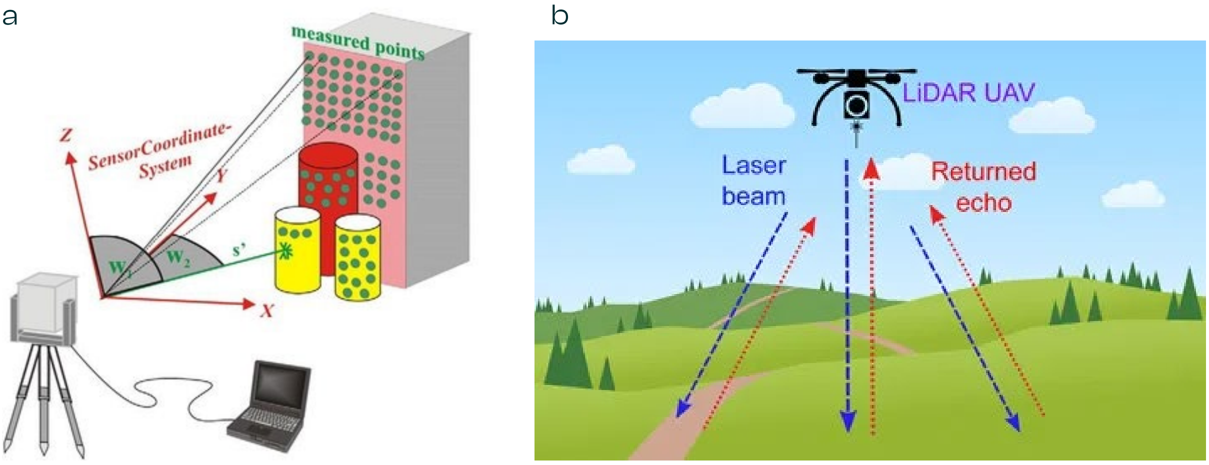


Figure 1 LiDAR Scanning (a) Terrestrial Laser Scanner on tripod[4] (b) UAV mounted laser scanning - airborne laser scanning[5].

LiDAR as a remote sensing technique is referred to as an example of ***active technology*** whereas aerial photography that may be used as part of photogrammetry is considered as ***passive technology***. This key distinction is because photography relies on sunlight or radiation to reflect off an external object whereas LiDAR systems emit their own radiation and measure how this radiation reflects from a target. The use of

LiDAR therefore is not limited to day light hours and can be less disrupted by environmental effects.

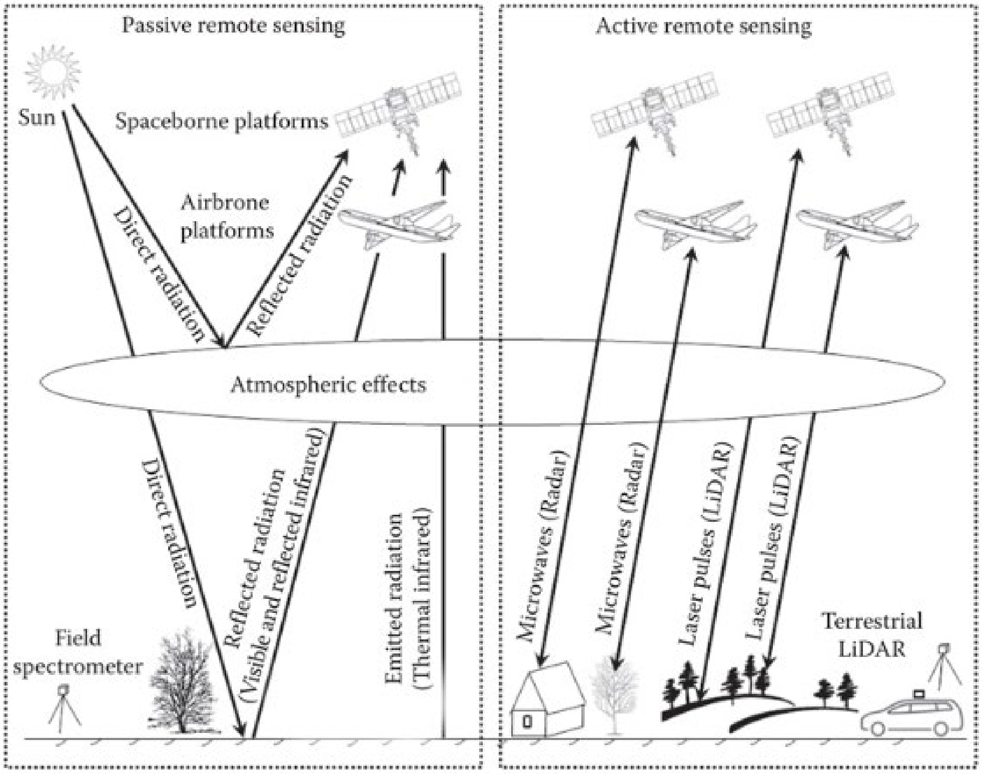


Figure 2 Passive and Active remote sensing[3]

2.2 Types of LiDAR

LiDAR may be classified by how the system is setup and functions. Some of the principal types include:

- Terrestrial Laser Scanning (***TLS***) – is a laser scanning system that operates on the ground. It may be a static (i.e. tripod mounted) or a dynamic (mobile vehicle/device) mounted system.
- Airborne LiDAR (***ALS***) – is a laser scanning system attached to an aircraft such as a UAV, plane or helicopter.
- Bathymetric – is a type of laser scanning that can be employed to penetrate the surface of water (up to approx. 50m in clear water)
- Satellite LiDAR – as the name suggests involves incorporating scanners onto satellites which can not only scan the earth's surface but also the atmosphere.

0Key Characteristics of TLS & ALS Scanning

Within the construction Industry, the two principal LiDAR scanning techniques frequently employed are ***TLS*** and ***ALS***, both of which can be used to capture 3d spatial data of the Earth's surface and structures. Terrestrial laser scanning onsite typical involves utilising surface or tripod mounted laser scanners which are strategically placed around the site or object of interest and moved as appropriate after each scan. Figure 3 illustrates some of the key components of such a system which includes a scanner capable of rotating 360 degrees horizontally (i.e. rotates about vertical axis) and a laser source that rapidly emits light which is typically reflected off a mirror that is rotating through 360 degrees vertically (i.e. rotates about the horizontal axis).

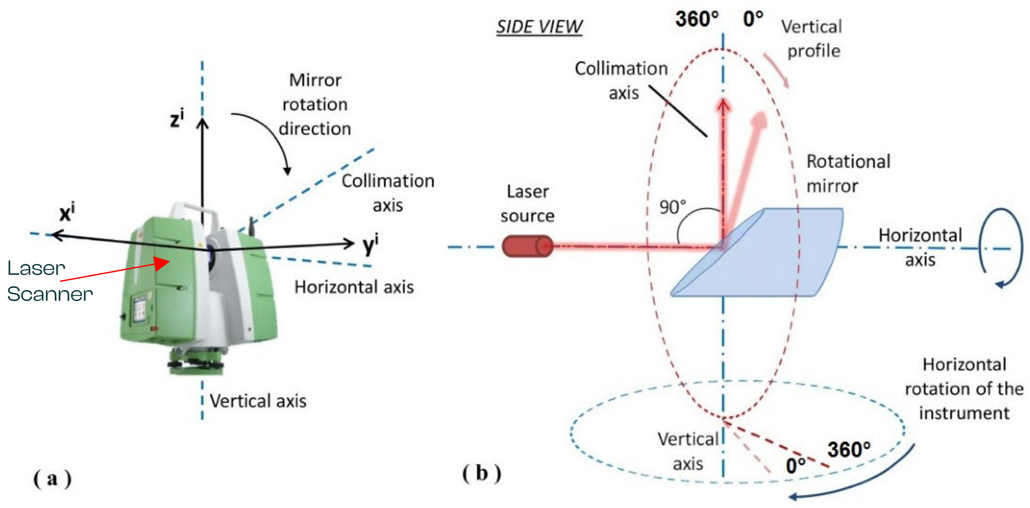


Figure 3 Key Components of a Tripod mounted TLS (a) Scanner[6] (b) Rotational Mirror within scanner[6]

ALS involves mounting laser scanners on airplanes, helicopters or UAVs. These scanners emit laser pulses towards the ground, and the reflected signals are used to create a 3D point cloud of the target surface and objects. Figure 4 illustrates some of the key components of the ALS systems which includes an Inertia Measurement Unit (IMU) to track the movement of the aircraft (pitch, roll and yaw) and a GNSS antenna for accurate recording of positioning (altitude and X,Y coordinates). Section 2.3 illustrates the key components of an ALS system in more detail.

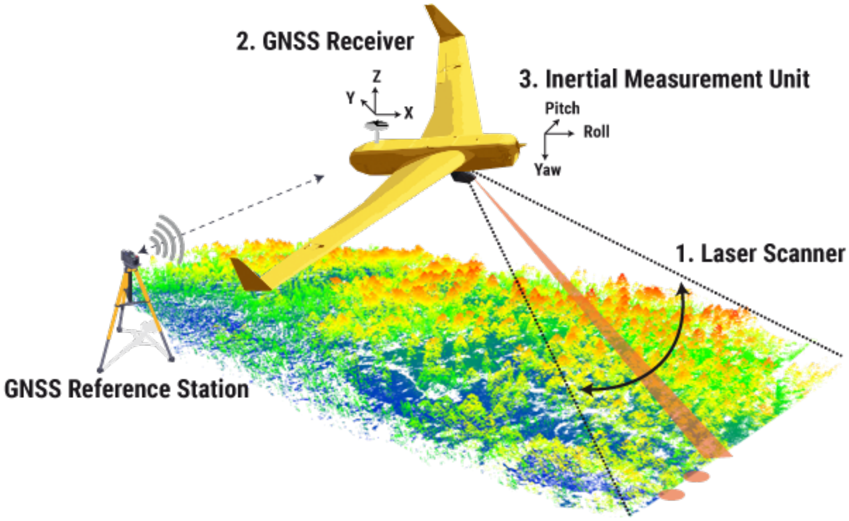


Figure 4 Key Components of an ALS system[16]

Both the TLS and ALS systems of laser scanning each have their own distinct advantages with regards to capturing 3d spatial data. Table 1 compares both laser scanning methodologies under some of the key criteria to consider before capturing spatial data in the field. Some of the typical applications for each method are also identified.

Table 1 Comparison of TLS and ALS techniques

	Terrestrial Laser Scanning (TLS)	**Airborne Laser Scanning (ALS)**
Location/Platform	TLS involves the use of stationary laser scanners that are set up on the ground or mounted on tripods. These scanners are placed at specific positions on the terrain or near the objects of interest.	ALS involves mounting laser scanners on aircraft such as UAS. These scanners emit laser pulses towards the ground, and the reflected signals are used to create a 3D point cloud of the Earth's surface and objects.
Range	Terrestrial laser scanners typically have a shorter range compared to airborne laser scanners. They can capture high-density data within a limited radius, usually up to a maximum of few hundred meters.	Airborne laser scanners have a much larger range compared to terrestrial scanners, allowing them to cover vast areas, typically several square kilometres, in a single flight.
Resolution	Due to the close proximity to the target, TLS can achieve very high data resolution. It can capture fine details of objects and surfaces with high accuracy.	ALS data can have lower resolution compared to TLS data because the scanner is capturing data from a higher altitude, resulting in a larger footprint for each laser pulse. Advancements in the technology now allow for a higher resolution but there is a balance to achieve between the intensity or resolution of the scan and the area to be covered.
Applications	TLS is commonly used for surveying small to medium-sized areas, detailed modelling of structures, archaeological sites, construction monitoring, and industrial applications, among others.	Fixed wing ALS is ideal for large-scale mapping, forest inventory, land-use planning, flood modelling, topographic mapping, and other applications that require extensive coverage of wide areas. Multirotor ALS is ideal for construction monitoring and asset management amongst others.
Data collection speed	TLS data collection is slower compared to airborne laser scanning because each scan position needs to be set up and processed individually.	ALS can cover large areas quickly, making it an efficient method for data acquisition over extensive landscapes

For the purpose of this training module, only the specific requirements and characteristics of ALS systems are considered for the remainder of this module.

2.3 LiDAR system components (ALS)

For many laser scanning operations, the LiDAR system is mounted on an aircraft or UAV. The key components of such as system are highlighted in Figure 6 and include:

- LiDAR Sensor: Pulses are fired form the LiDAR sensor at near infrared bands as the aircraft flies. Figure 5 illustrates the wavelengths on the electromagnetic spectrum.

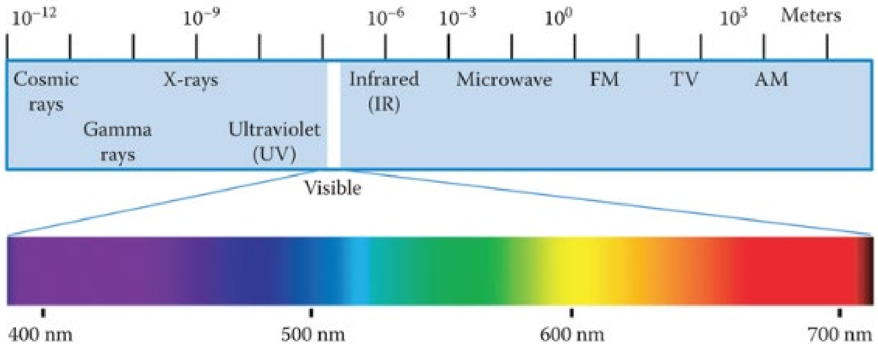


Figure 5 Electromagnetic spectrum[3]

- GPS Receivers: GPS receivers track the altitude and location of the aircraft or UAV so that accurate positioning of the aircraft can be established for processing of data.
- Inertial Measurement Units (IMU): The IMU tracks the pitch, roll and yaw of the aircraft so that accurate measurement of the aircraft movement and emission/return of laser pulses can be established.

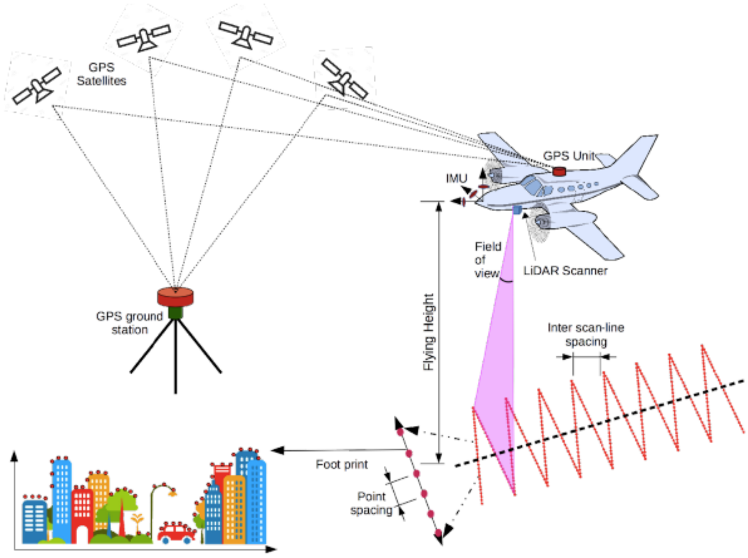


Figure 6 ALS Components[13]

- Data Recorders or CPU: An onboard CPU unit records all of the pulse information which are then translated into exact locations (x,y,z).

Where mapping operations are being carried out over large areas, it is common practice to employ fixed wing aircraft or UAV. However, where smaller areas or specific objects/structures are to be scanned, multi rotor UAVs are frequently employed.

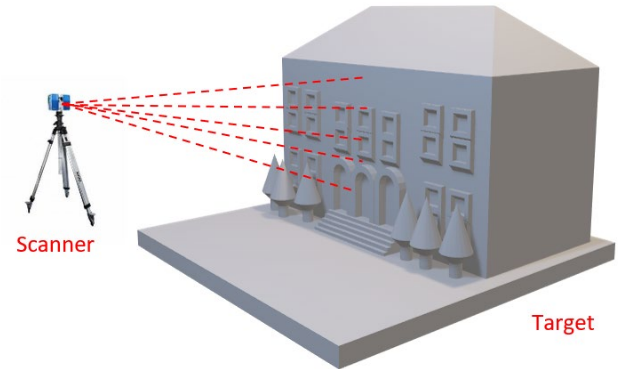
Figure 7 Muti Rotor DJI M300 with L1 Laser Scanner[17]

Figure 8 L1 Zenmuse DJI Laser Scanner[10]

3. LIDAR Data

3.1 Data types recorded during LiDAR scanning.

During a LiDAR scan, several different types of data (Field measurements, Metadata, etc) may be captured to help create and supplement an accurate 3D representation of the scan area or object. While the data types may vary depending on the application and scanner type, some of the most common data types are identified in Figure 9 and Table 2 below:



	Scanner	**Target**
Field Measurement	Distance Pulse rate Horizontal and Vertical Angles	Position (X,Y,Z) Intensity (I) Colour (RGB)
Metadata	Time of Capture Environmental Conditions Calibration details Service Provider Information	Project Name/Location Control Network Business Intelligence

Figure 9 LiDAR Data Types

Table 2 LIDAR Data Types and Parameters

Data Types	Description
Point Cloud Data	The fundamental output of a LiDAR scan is a point cloud. Each point within the point cloud represents a specific location in the 3D spatial environment. Collectively these points form a 3D model of the surface, area or object that was scanned.
Scan Parameters	The LiDAR system's scan settings have a significant influence on the quality, resolution and accuracy of the scan. Parameters such as pulse rate (pulse/sec) and scanning resolution are typically recorded.
GPS Position Data	LiDAR systems record the geographic coordinates (latitude, longitude) and elevation (altitude) of each laser pulse's point of origin and its return point. This information allows for accurate calculation of distances and for positioning in the real world.
Intensity Data	Intensity is a measure of the return strength of the laser pulse that generated the point. Every laser return or echo has an Intensity value which can provide additional information about the reflectivity or material properties of surfaces which helps to distinguish between different surfaces.
RGB Data	Many LiDAR systems are equipped with cameras that capture colour imagery or RGB data. RGB data can be embedded with the point cloud to create a visually realistic and coloured 3D representation of the scanned object or area.
Classification Data	Points in a point cloud can be classified based on the objects or surface they returned from (e.g. ground, water, building etc) which can help with data analysis and in interpretation during processing.
Return Number and Number of Returns	Each laser pulse can result in multiple returns if it interacts with multiple surfaces. The return number indicates which return it is (first, second, etc.), and the number of returns indicates how many returns were recorded for that pulse.
Calibration Data:	Some LiDAR systems capture calibration information, which helps correct for sensor imperfections and optimize the accuracy of the point cloud.

3.2 Data Format and Structure

There are a number of point cloud file formats that the lidar data can be encoded including LAS (.las), LAZ (.laz) and E57 which are amongst the most common. The LAS format is employed by the American Society of Photogrammetry and Remote Sensing (ASPRS). Regardless of which file format is chosen, the vast majority are ultimately some variations of the XYZ-I-RGB position-intensity-colour scheme as highlighted in Figure 10. LAS is often the industry standard for storing airborne LiDAR data and commonly used for GIS applications. E57 has broader applications for laser scanning allowing images and metadata to be stored with the point cloud. Both formats can be converted into other formats such as .TXT or Shapefiles. LiDAR point cloud data can contain 'classification of returns', which assists the end user in determining the type of object scanned, e.g. ground, buildings or water. This can enable other data models such as DSMs and DTMs.

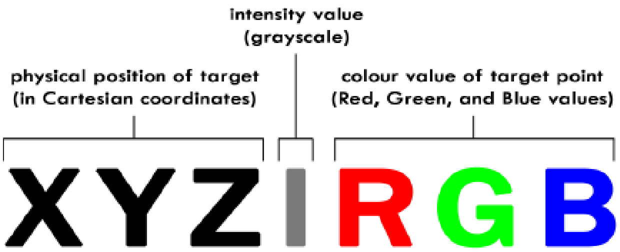


Figure 10 LiDAR Data Formats[8]

While there are several propriety hardware and software solutions that can convert LiDAR data into a multitude of data formats, it is important for those procuring LiDAR data to determine what file format will ensure best integration of data into existing systems (such as asset management systems) to ensure interoperability.

With respect to the LAS formatting type, the most important information describing each pulse are categorized as X, Y, Z, I, N, R, C. The parameters are as follows:

- X, Y and Z are the coordinates of the echo locations.
- I indicate the intensity or strength of the echo.
- N represents the number of returns (echoes) received from a single pulse and
- R indicates the order of these echoes, or the return number. For example, a combination of N = 2 and R = 1 indicates that two echoes were recorded from this pulse (N = 2) of which this record is the first (R = 1). It is common for echoes in public data to be classified into categories.
- Column C indicates these categories for this classification.[8]

X	Y	Z	I	N	R	C
597847.589	7336016.990	329.020	1	3	1	3
597847.290	7336017.230	325.050	1	3	2	3
597846.979	7336017.490	320.780	1	3	3	1
597845.609	7336017.429	319.820	14	1	1	1
597842.969	7336017.230	319.330	18	1	1	2
597840.359	7336017.009	319.060	17	1	1	2
597838.520	7336016.200	328.500	8	1	1	1
597836.849	7336016.370	323.710	5	2	1	3
597836.469	7336016.660	318.960	0	2	2	2

Figure 11 LAS (.las) LiDAR Data Format[8]

4. LIDAR Applications

Unmanned Aerial Vehicles (UAVs) equipped with LiDAR technology have found numerous applications in the construction and civil engineering industries. When compared to other aircraft such as helicopters or planes, scanning with UAVs can offer significant benefits in terms of efficiency, accuracy, and cost-effectiveness. The following section identifies some examples of the novel ways in which UAV LiDAR is being used for construction and civil engineering applications. This is not an exhaustive list, and it is also worth noting that UAV LiDAR is being adopted by many different industries outside of the construction industry. The combination of UAVs and LiDAR technology provides construction and civil engineering professionals with highly accurate, up-to-date, and easily accessible data. This enables better decision-making, improved project management, and enhanced safety across a wide range of applications in the industry.

4.1 Survey Mapping and Site Inspections/Analysis.

UAV LiDAR can quickly and accurately create topographic maps of construction sites. This data helps engineers and planners understand the terrain, existing structures, and vegetation. It aids in site selection, planning, and designing infrastructure projects. LiDAR-equipped drones can perform accurate volumetric calculations of stockpiles, excavation sites, and landfills. This information is crucial for project management, tracking progress, and managing material quantities. Regular LiDAR scans of a construction site can provide real-time insights into the progress of the project. This helps in identifying delays, resolving issues, and maintaining project schedules. During construction, UAV LiDAR can be used to capture the as-built condition of a project. This data can be compared to design models, helping identify deviations and ensuring that construction is proceeding as planned.

Figure 12 Harbour LIDAR scan [9]

4.2 High foliage density surveying.

0Plant cover penetration with LIDAR

For LiDAR applications in areas that have a high density of foliage like forests, a significant portion of the LiDAR rays do not travel to the ground level because of branches, leaves and other objects obstructing the path. LiDAR (laser beams) cannot penetrate through these objects. The results of LiDAR scans in such areas will differ depending on the seasons of the year (winter typically has less foliage – LIDAR scan can be more successful; opposite is true for spring/summer there where there is increased foliage and rays cannot travel to the ground level).

Therefore, when considering ALS scans with high density plant coverage, the focus for point cloud models, are points that successfully travelled between objects reaching the ground level.

It is worth noting that the scanning angle is one of the key factors for a successful mission. The figure below presents an example of laser impulse penetration in wooden areas considering vertical field of view. As you can see, some laser rays are penetrating all the way to the ground, while others subject to the density of the leaf coverage will return to LiDAR before reaching the ground.

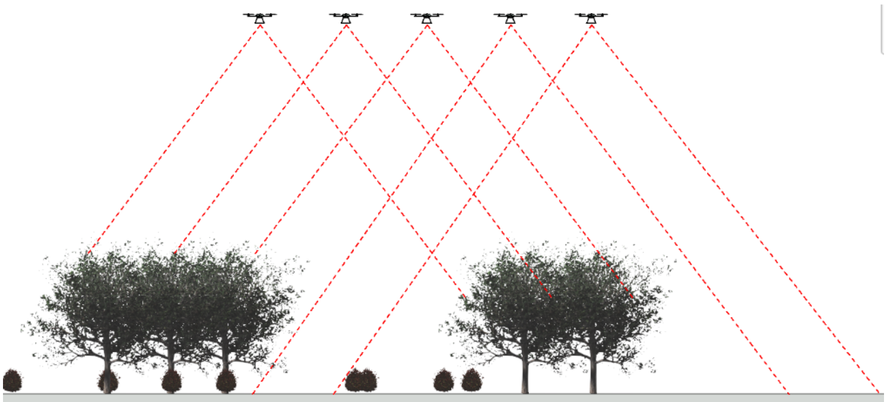


Figure 13 Example of laser beam penetration through trees.

The figure below shows an example of a forest scan utilising ALS.

Figure 14 Example of a forest scan[9]

To plan ALS missions like those described above, a UAS pilot needs to consider a number of factors when selecting the most appropriate LIDAR equipment and scan settings based on the environment:

1. **Pulse repetition rate/frequency** – number of pulses of light sent from LiDAR scanner per second. Higher pulse repetition rate means higher point density of the LiDAR data; increased probability of LiDAR pulses passing through foliage voids to measure ground surface.
2. **Field of View –** to increase the probability of LIDAR penetration through foliage,
   many scanners have the ability to increase their field view through vertical and horizontal rotation of the sensor during a mission rather than utilising a static sensor position.

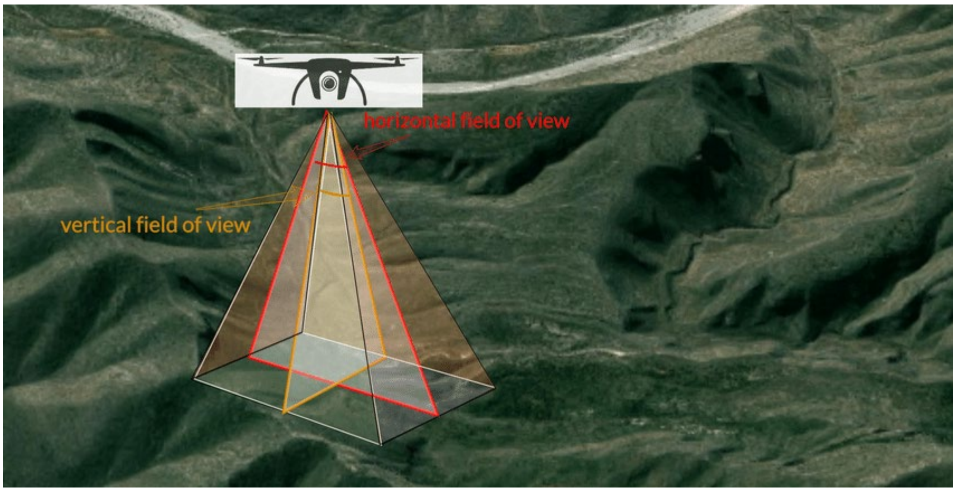


Figure 15 Field of View[19]

3. **Number of Returns (echoes) –** each LiDAR sensor has an ability to detect a number of returning echoes (after hitting a solid object) from each laser pulse. The higher the number of return echoes detected the better range sensitivity and increase resolution of scanned vegetation structure.
4. **Laser Wavelength –** there are two typical wavelengths used in the majority of UAS LIDAR units: 905 and 1550 nm. The 1550 can often be the more efficient option to scan vegetation due to its high laser power allowing for scanning to occur at a high altitude (safer option for tall trees and bigger clearance). It also has more sophisticated processing, more returns and lower data noise. The 905nm performs better in more humid and wetter environments. The 905 should be selected for low vegetation and more flat terrain.
5. **Beam divergence –** represents divergence of photons from a laser beam (in cone shape) from LIDAR sensor. Figure below presents two LIDAR sensors with different beam divergence.

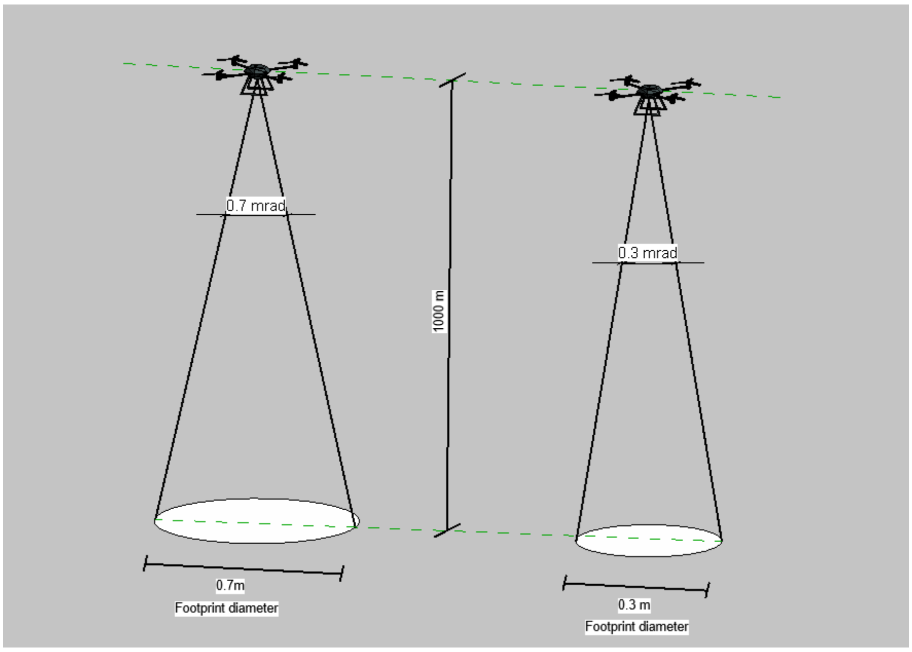


Figure 16 Different LIDAR beam divergence examples (not to scale)

As mentioned previously, figure 13 presents two Drones with different beam divergence LIDAR sensors. It is also crucial to mention that that the lower the beam divergence the higher accuracy of the scan.

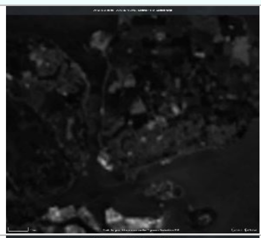
Multispectral LiDAR (MS LiDAR)

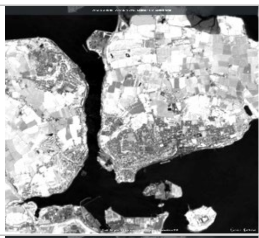
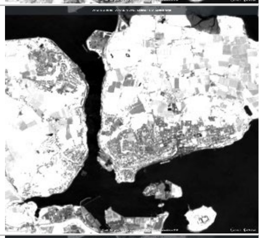
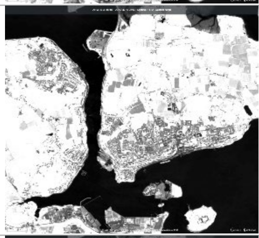
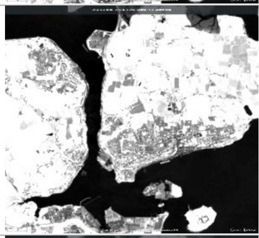
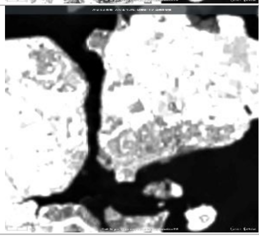
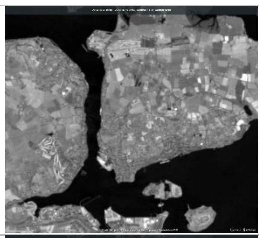
It is worth mentioning that LIDAR recently is combining its capabilities with multispectral imaging. Multispectral technology is already widely used i.e. Sentinel-2 satellite. Multispectral imaging is using number of wavelengths ranges collecting images in different bands of light spectrum. This technique helps in determining land coverage, type and conditions of planting.

In the forest surveying and management multispectral camera can help in recognising tree species, its health and biomass.

As mentioned, there are number of bands which this equipment can operating:

Table 3 Sentinel-2 satellite images per wavelength/bands[20]

Sentinel-2 Bands	Central Wavelength (micrometres)	Example of image for Cork harbour
Band 1 – Coastal aerosol	0.443	
Band 2 - Blue	0.490	
Band 3 - Green	0.560	
Band 4 - Red	0.665	
Band 5 - Vegetation Red Edge	0.705	

Band 6 - Vegetation Red Edge	0.740	
Band 7 - Vegetation Red Edge	0.783	
Band 8 - NIR	0.842	
Band 8A - Vegetation Red Edge	0.865	
Band 9 - Water vapour	0.945	
Band 10 - SWIR - Cirrus	1.375	N/A
Band 11 - SWIR	1.610	
Band 12 - SWIR	2.190	

MS LIDAR systems will combine introduce other wavelength imaging capability.

Optech`s Titan system combines three wavelengths[15]:

- Visible green light – 532 nm
- Near Infrared (NIR) – 1064 nm
- Infrared (IR) – 1550nm

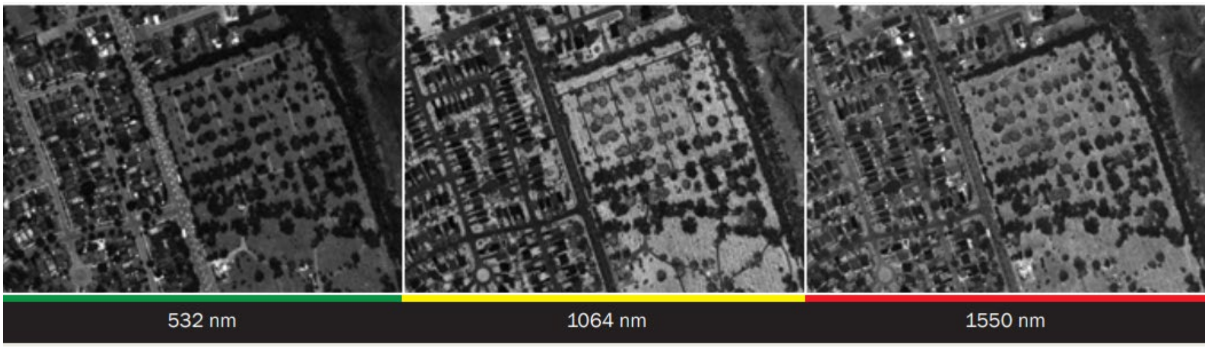


Figure 17 Example of MS LIDAR Images

4.3 Safety Inspections and Structural Health Assessments

LiDAR-equipped drones can assess the condition of existing structures, such as bridges and buildings. By detecting deformations, cracks, and other anomalies, engineers can make informed decisions about maintenance and repairs. Drones with LiDAR can access hard-to-reach or hazardous areas, reducing the need for personnel to work in risky environments. This is particularly useful for inspecting tall structures or sites with dangerous conditions. The figure below shows an example of a Tower bridge scan with the original processed point cloud on the left and an elevation filter applied in the image to the right.

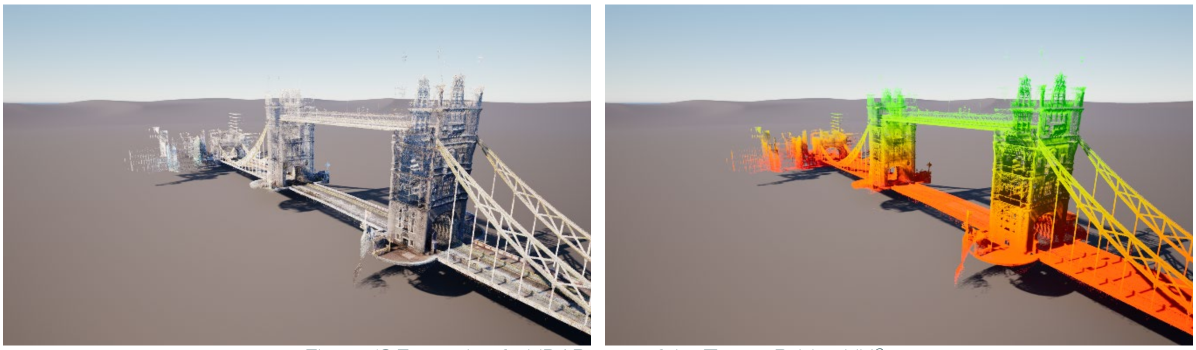


Figure 18 Example of a LIDAR scan of the Tower Bridge UK[9]

4.4 Flood Modelling and Environmental Impact Assessments

LiDAR-generated elevation data is crucial for creating accurate flood models and developing effective flood management strategies. LiDAR can accurately capture vegetation density and land cover. This information is useful for assessing environmental impacts, such as the potential for flooding, erosion, and habitat disruption. UAV LiDAR data can support urban planning and land development projects by providing accurate information about land use, existing structures, and natural features.

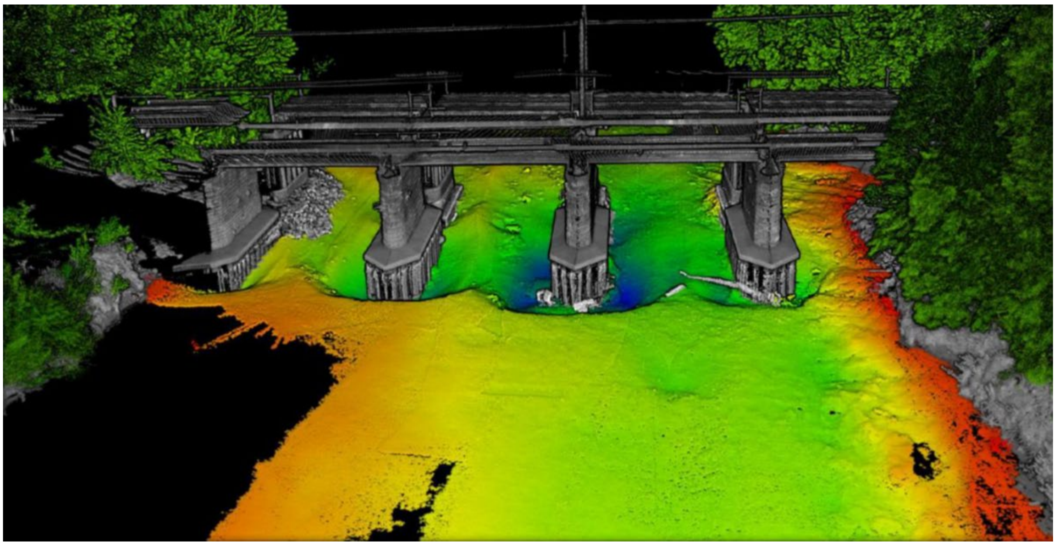


Figure 19 Example a River Eden LIDAR scan[14]

4.5 Utility and Infrastructure Management

LiDAR is used to survey and map utility networks, such as power lines and pipelines. This data aids in planning maintenance, upgrades, and expansions.

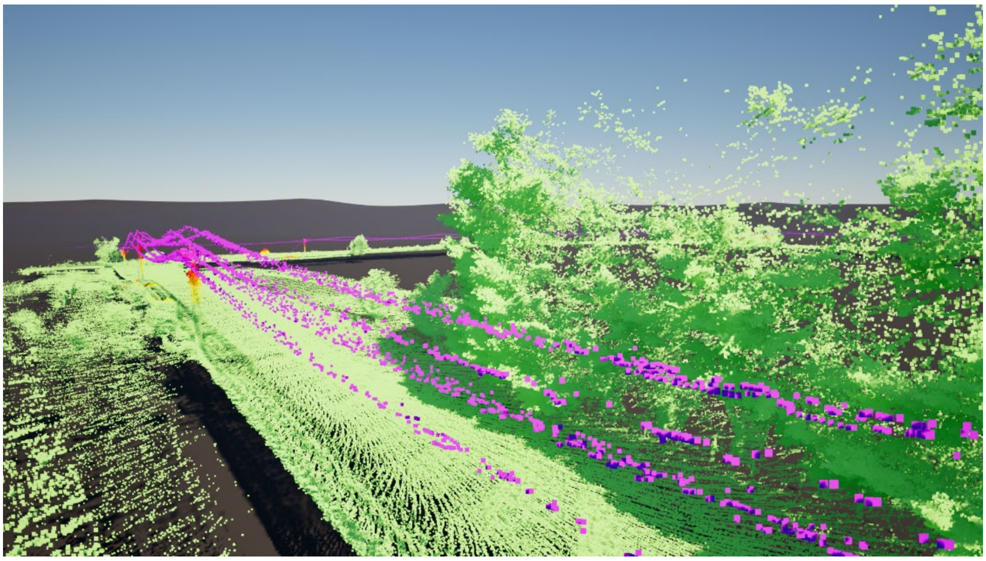


Figure 20 Power line scan analysis example [9]

5. LIDAR field Capture and Proceeding Methodology

When considering the use of LIDAR equipment in conjunction with UAVs the operator needs to remember to plan their mission accordingly as outlined in Module 2 "Flight planning and reporting " of this programme.

5.1 Hardware

There are a number of available LiDAR sensor solutions on the market and typically most Drone manufacturers have a LIDAR solution that integrates into their own UAV systems.

Some of the more popular include DJI drones (i.e. M300 with LIDAR solution DJI Zenmuse L1) which typically retails for approx. €10,000. Again, it is important to mention that this industry is constantly changing and the palette of solutions is increasing.

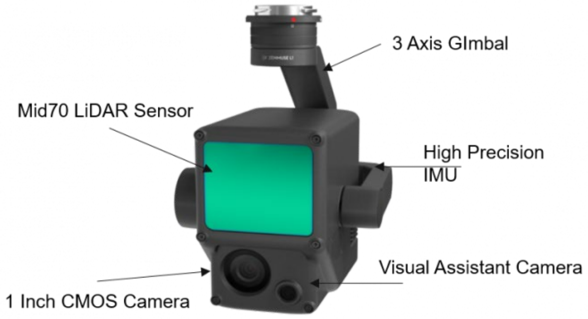


Figure 21 An example of LIDAR for Drone equipment [10]

It is imperative to select equipment whose properties match the requirements for the specific type of missions. Some of the key parameters to consider are identified in the following table for some of the most widely used LiDAR sensor currently available:

Table 4 Comparison of LIDAR sensors details[11]

Model	Roegl mini VUX-1DL [11]	Velodyne VLP-16[12]	Quanergy M8[13]	L1 Zenmuse DJI [14]
Wavelength (nm)	Near-infrared	903	905	905
Measuring Range (m)	3-200	<100	0.3-200	190m@10%, 100klx; 450m@80%, 0klx
Accuracy/Precision (mm)	±15/10	±30	±30	30 @ 100 m distance
Max. Pulse Repetition Frequency (PRF) (Khz)	100	-	-	200
Max. Effective Measurement Rate (kPts/sec.)	100	300/600	430	Single return: max. 240,000 pts/s ; Multiple return: max. 480,000 pts/s
Scan Frequency (Hz)	20-150	5-20	5-30	one/two returns: 80K/s, 160K/s, 240K/s; three returns: 80K/s, 240K/s
Field of View (FOV) (Degrees)	-23-+23	-15-+15 (Vertical) 360 (Horizontal)	-17-+3 (Vertical) 360 (Horizontal)	Non-repetitive scanning pattern: 70.4° (horizontal) × 77.2° (vertical) ; Repetitive scanning pattern: 70.4° (horizontal) × 4.5° (vertical)
Max. Operating Flight Altitude (AGL) (m)	80	-	-	50m-120m

Angular Resolution (degree)	0.001	2 (vertical) 0.1-4 (horizontal/azimuth)	0.03-0.2	-
Echoes	Up to 5 echoes	Up to 2 echoes	Single echo	-
Weight (kg)	2.4	0.83	0.9	0.930±0.01

Table 3 presents LIDAR sensors that could be used for any drone that is matching manufacturing specification typically dictated by payload, available hardware, framing, room for installation and software. Additionally, Table 3 highlights some of the main parameters for LIDAR solutions however there are more parameters that needs considering: power, IP rating, operating temperature, storage temperature, output file formats, resolution).

5.2 Pre-flight setup

As mentioned at the beginning of this section; in order to execute the mission, operators need to follow certain procedures to prepare the drone and related equipment (more detail in Module 2).

STEP 1 RTK or PPK as precision of scan setup

LIDAR set-up itself would be slightly different with specific Drone-LIDAR setup. In order to have a well-executed, high accuracy scan, the initial GNSS (Global Navigation Satellite System) setup should have either Real Time Kinematics (RTK) or Post-Processing Kinematics (PPK) technology:

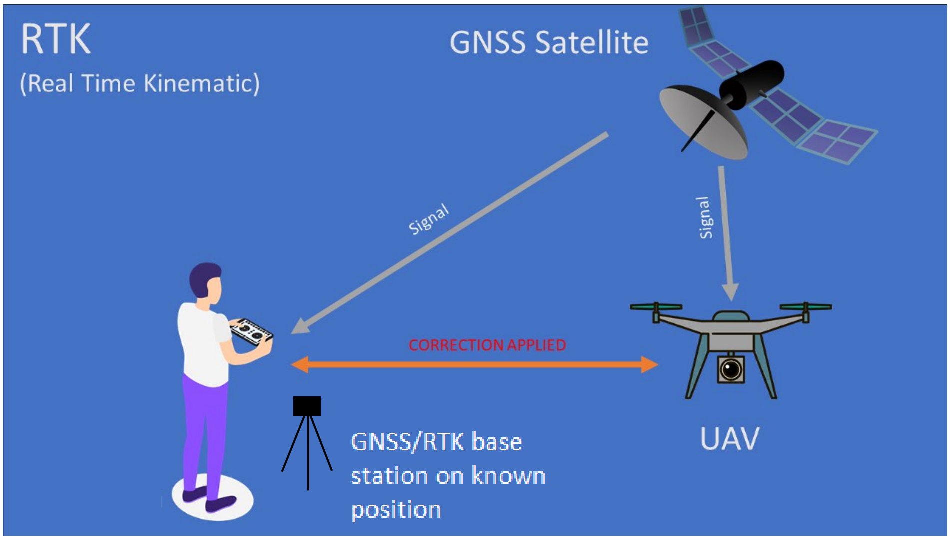


Figure 22 RTK Explained

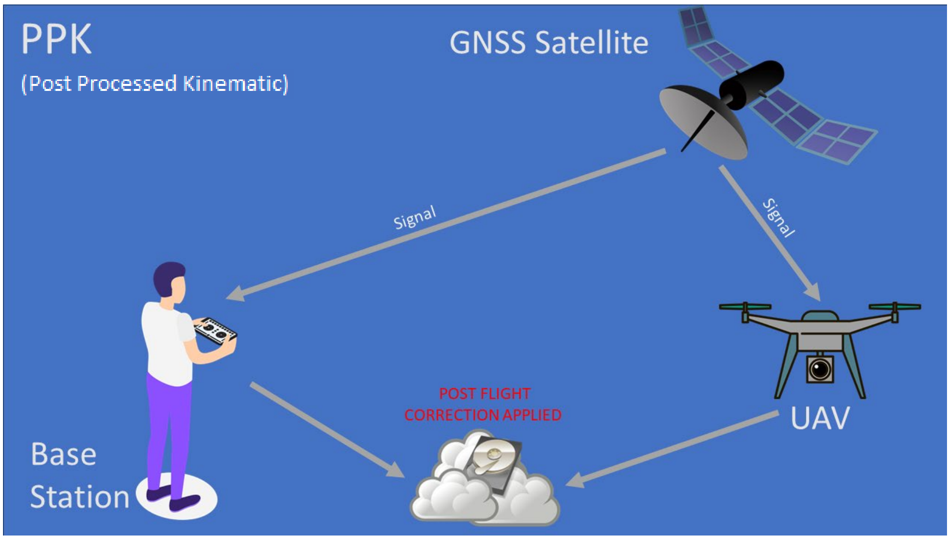


Figure 23 PPK Explained

NOTE: If RTK stability can`t be guaranteed (i.e. Weak satellite signal) then PPK should also be used.

The main difference between these two approaches is the initial time for position correct to happen:

- RTK approach does correction during the flight,
- PPK all corrections happen after the initial flight.

STEP 2 Inertial Measurement Unit - IMU calibration

In order to assure correct LIDAR and final cloud accuracy drone operators need to calibrate IMU-inertial measurement unit. Since each drone manufacturer will have specific steps to be taken in order to complete this step. As an example, DJI L1 LIDAR requirement is to do it before, during (every 100s) and after the flight. These steps will ensure correct accuracy.

Typically, calibration involves UAV to ascend to certain altitude then flying forward 30m and then backwards the same distance.

NOTE: Make sure that IMU calibration is done preferably in obstacle free area.

STEP 3 RGB Camera calibration

Typically, RBG Camera only needs to be recalibrated if there are visual issues with data captured. One of the examples are so called ghost lines in point cloud scan.

NOTE: Each manufacturer will provide instructions on how to recalibrate a RGB Camera.

STEP 4 Flight Mission Planning – selection of correct flight parameters and setup for missing type.

Depending on type of an aircraft and LIDAR equipment, manufacturer will advise on recommended parameters, these would include:

- FOV – Field of View
- Ground Swath – area imaged on the surveyed surface
- Altitude of capture
- Speed
- Flight path spacing

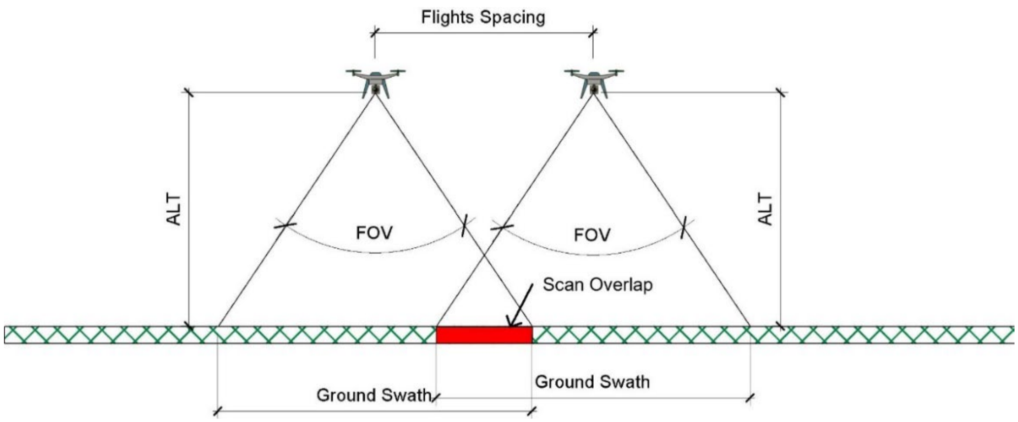


Figure 24 Flight planning parameters

The Figure above presents the flight parameters and their impact on scan overlap – scan quality/density.

Additionally, parameters to define before a mission include:

- Scan resolution [pixels]
- Focal length [mm]
- Image rate [sec/frame]
- Data requirement

Co-funded by the Erasmus+ Programme of the European Union

5.3 Inflight capture and capture software

Inflight capture apart from setting and preflight planning parameters will focus on software and its applications. Most of new LIDAR drone technology would have app pre-installed that helps to plan the flight (not only for LIDAR).

Planning data capture (as mentioned Step 4 of mission planning) it is important to decide (based on type of survey i.e. topography, riverbank, powerlines surveying) the route of drone flight.

In order to plan routes, one needs to acquire/use a detailed and up-to-date map of the area (UAV manufacturer`s sensitive). Acquired maps can be used in drone control app for planning. It is imperative to understand map file (very often ***.tiff** file type) coordinate system.

Figure 25 DJI Terra GUI

As mentioned above drone controller typically, would have pre-installed app that allows for path planning.

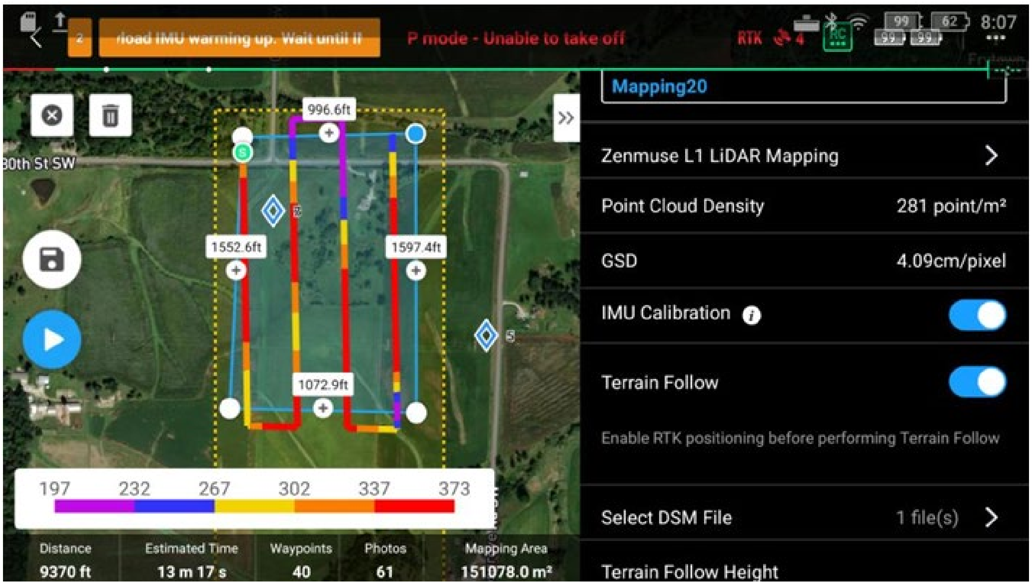


Figure 26 DJI Pilot App - mission planning example [12]

Capture is achieved during drone flight. Files are saved onto Drone storage it can be transferred after the mission is complete to a Desktop PC or other Operations System for processing.

5.4 Processing & Software

When dealing with LIDAR drone data processing one has to consider a platform. There is a number of available software packages (i.e. DJI terra, PIX4D). Each software would have specific instructions to follow.

As mentioned in previous chapter data needs to be imported into post processing software.

Raw data would typically include information:

- LIDAR point could raw data
- LIDAR camera calibration
- IMU calibration
- Visual calibration
- Inertial Navigation
- Visual data
- RTK base station data
- RTK sub-antenna data
- JPEG files - pictures

After successful import to post-processing software data is ready to utilise.

RAW data from LIDAR will be compiled into LAS file. Different software will produce variety of options (i.e. point cloud density and output coordinate system) for output before data is processed and point cloud is generated.

Generally speaking, post-processing could be defined as 5 steps:

A. Trajectory processing – post flight – this step involves check for potential errors with trajectory
B. Point cloud generation – as mentioned previously following output parameters input a point cloud is being generated.

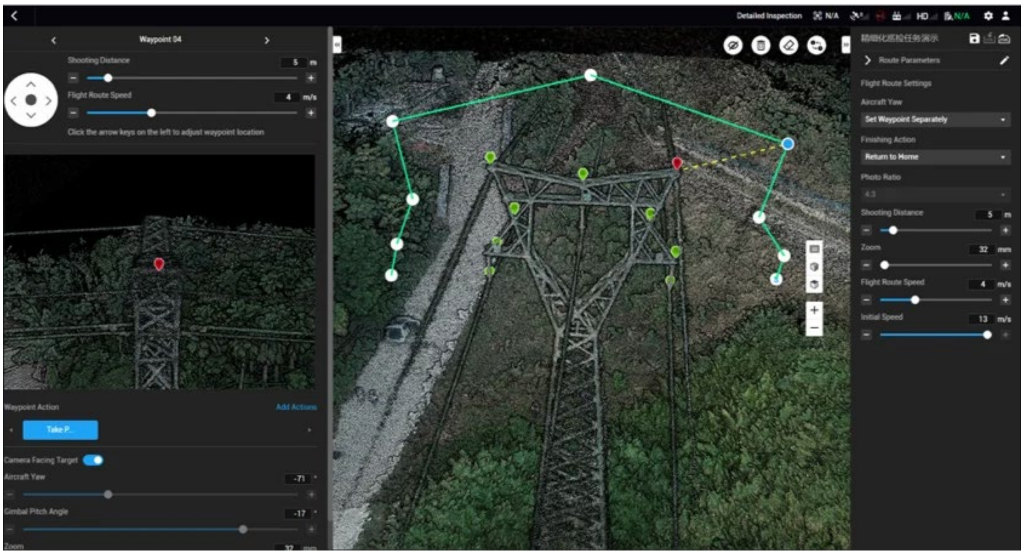


Figure 27 Example of a point cloud generated for power line inspection.[12]

C. Refining point cloud accuracy
D. Colorization – this step is to add colours to a point cloud to achieve more detailed view of inspected objects/areas. The reasoning behind this step is to manipulate image with alternative RGB (red, green, blue) and receive as a result an additional intelligence from the point cloud.

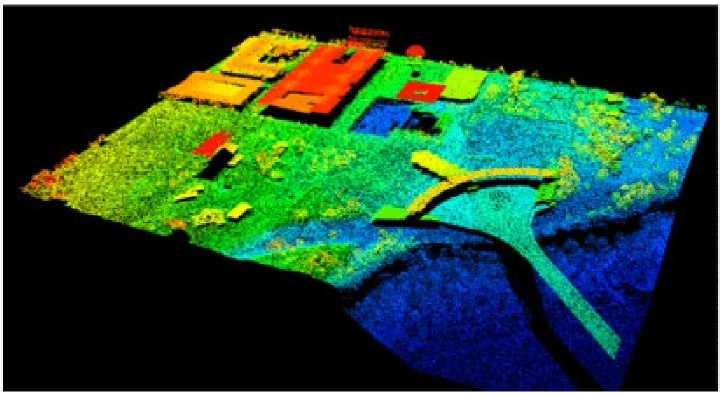


Figure 28 Using colour intensity per height[13]

E. Classification – this step allows to assign a "class" to different types of elements/objects within point cloud. These could be different categories such as: ground, water, building etc. This allows the viewer to decide on visibility of each category to enhance the point cloud processing.

5.5 Data Output

One of the main data outputs is a processed point cloud file typically LAS or LAZ file, containing different information (detailed in chapter 0). Some software packages allow you to export

- mission details (data included in raw LIDAR package), - file type dependant of software
- pictures captured during mission, (JPEG, PNG, BMP etc.)
- 2D maps (i.e. Geotiff – geo referenced picture; TIFF)
- 3D models (i.e. OBJ, B3DM, OSGB, PLY, S3MB, I2S)

Data output is typically suggested by the survey contract and final use of data.

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